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TNT EQUIVALENCY OF NITROGLYCERINE

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Engineering Mechanics Division
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

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TNT EQUIVALENCY OF NITROGLYCERINE

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Prepared by

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James J. Swatosh, Jr.
Hyla S. Napadensky

Under the technical direction of:

Picatinny Arsenal
Dover, New Jersey 07801

for

Olin Corporation
Badger Army Ammunition Plant
Baraboo, Wisconsin 50329

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FOREWORD

IIT Research Institute (IITRI) has conducted an experimental program to determine the TNT equivalency of nitroglycerine. The work was conducted for Olin Corporation, Badger Army Ammunition Plant, Baraboo, Wisconsin under subcontract OB-P 50329. This work was conducted as part of the Picatinny Arsenal program on Safety Engineering in support of the U.S. Army Ammunition Plant Modernization effort. Technical guidance was provided by Mr. R. Rindner of the Manufacturing Technology Directorate, Picatinny Arsenal, Dover, New Jersey which has the overall responsibility for the above type program. The experiments were conducted at the Badger Army Ammunition Plant. Olin personnel who contributed to this effort include G. Shalabi, J. Ramnarace, R. Johnson, F. Fish, C. Brayer and S. Catlin. In addition to the authors, IITRI personnel who have made material contributions to this program are A. Humphreys, R. Joyce, D. Hrdina, and J. Daley. This document entitled "TNT Equivalency of Nitroglycerine," is the final report on this effort.

Respectfully submitted,
IIT Research Institute

J. J. Swatosh, Jr.
Research Engineer

H. S. Napadensky
Manager
Safety Research

Approved:

K. E. McKee
Director of Research
Engineering Mechanics Division

ABSTRACT

TNT equivalency tests were conducted on Nitroglycerine. One-, two-, and four-pound charges were ignited with various size boosters ranging from a number 6 blasting cap to 127 grams of C4 explosive. In one case a hot wire was successfully used to detonate the nitroglycerine sample. Pressure and positive impulse was measured in the scaled distance range of 4 to 50 $ft/lb^{1/3}$. Peak pressure TNT equivalency ranged from 240 to 80 percent in that scaled distance range and the impulse TNT equivalency ranged from 190 to 120 percent. No variations in the explosive output of Nitroglycerine were observed when different size boosters were used. Similarly no effect of charge size on TNT equivalency was observed.

ft./cu root lbs.

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LIST OF ILLUSTRATIONS

1. OBJECTIVE

The objective of this program was to experimentally determine the TNT equivalency of Nitroglycerine.

2. SUMMARY

Thirty tests were conducted to determine the TNT equivalency of Nitroglycerine. Free field pressure and impulse measurements were made in the scaled distance range of approximately 4 to 50 $ft/lb^{1/3}$. One, two, and four pound Nitroglycerine samples were detonated in plastic beakers at ground level with various size boosters.

The explosive output of the Nitroglycerine samples was not affected by increasing or decreasing the booster size and was independent of of charge weight. Once the sample ignited its scaled blast output was constant at a given scaled distance.

The peak pressure TNT equivalence of Nitroglycerine at a scaled distance of 4 $ft/W^{1/3}$ is 240 percent and is 80 percent at a scaled distance of 50 $ft/lb^{1/3}$. The impulse TNT equivalence at a scaled distance of 4 $ft/lb^{1/3}$ is 190 percent and is 120 percent at a scaled distance of 50 $ft/lb^{1/3}$.

3. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be made as a result of these experiments.

- Nitroglycerine, a very sensitive material, yields a large explosive output when ignited.
- The explosive output of Nitroglycerine does not change with variations in the magnitude of the ignition stimulus (i.e., Not within the range of booster stimuli provided in this test series).
- The explosive output of Nitroglycerine does not change with variations in the magnitude of the charge weight (i.e., not within the range of charge weights tested in this series 1 to 4 pounds).

- Extrapolation of the data herein to scaled distances lower than 4 ft/lb$^{1/3}$ or greater than 50 ft/lb$^{1/3}$ may give unrealistic results because the blast output curves for TNT and Nitroglycerine appear to be diverging.

As a result of this program the following recommendations are made. It is not felt that their immediate implementation is mandatory in order to proceed with the Nitroglycerine plant construction. However, these recommendations should be considered for inclusion in a hazard classification and analysis program.

- Make pressure and impulse measurements in higher pressure ranges, 200 to 1000 psig, and determine TNT equivalency. This must be done with large size charges to minimize the effects of having to record very peaked pressure-time waves.

- Experimentally determine the minimum stimuli, shock, heat, etc., to ignite Nitroglycerine and determine if there are variations in its explosive output.

- In conjunction with the above recommendation, determine safe separation distances between minimum stimuli and Nitroglycerine sample. Determine safe separation distance between two Nitroglycerine samples to prevent sympthetic detonation.

- The TNT equivalency of Nitroglycerine for close-in effects should be based on impulse and a value of 190 percent is indicated. At interline distance a pressure equivalency should be employed and a value of around 125 percent is recommended.

4. INTRODUCTION

A series of tests were conducted on samples of Nitroglycerine at Badger Army Ammunition Plant, Baraboo, Wisconsin. Three different sample sizes were tested using several different types of igniters. Blast pressure and impulse measurements were made and TNT equivalencies were determined.

5. TEST CONFIGURATIONS

The tests were performed in a relatively flat field located near the Nitroglycerine manufacturing facilities at Badger Army Ammunition Plant. A schematic plan view of the area is illustrated in Figure 1. A circular area approximately 150 feet in diameter was mowed free of tall grass at ground zero. IITRI's barricaded instrument trailer was located approximately 400 feet from ground zero. Pathways to the instrument trailer and Nitroglycerine Facility were also mowed free of tall grass.

Six pressure gages were flush mounted in metal plates which were, in turn, flush mounted to the ground with stakes. They were located at intervals on a radial line from ground zero. Cables from the gages to the instrument trailer were buried in the immediate area of the charge and were laid on top of the ground the rest of the way to the instrument trailer. Appendix D gives a detailed description of the instrumentation system.

Two cameras located near the instrumentation trailer were used to visually record the test events. A Fastax high speed camera, operating at approximately 3000 frames per second, was time sequenced with the firing circuit. A 16mm Bolex camera, operating at 32 frames per second, was used to record late-time or slow-time events, should they have occurred. Five fiducial poles were erected behind the charge with respect to the cameras to give a distance reference.

Figure 2 illustrates the charge configuration for these tests. Steel stakes were welded to the four corners of an 8 x 8 x 1-inch-thick mild steel plate. The stakes were driven into the ground,

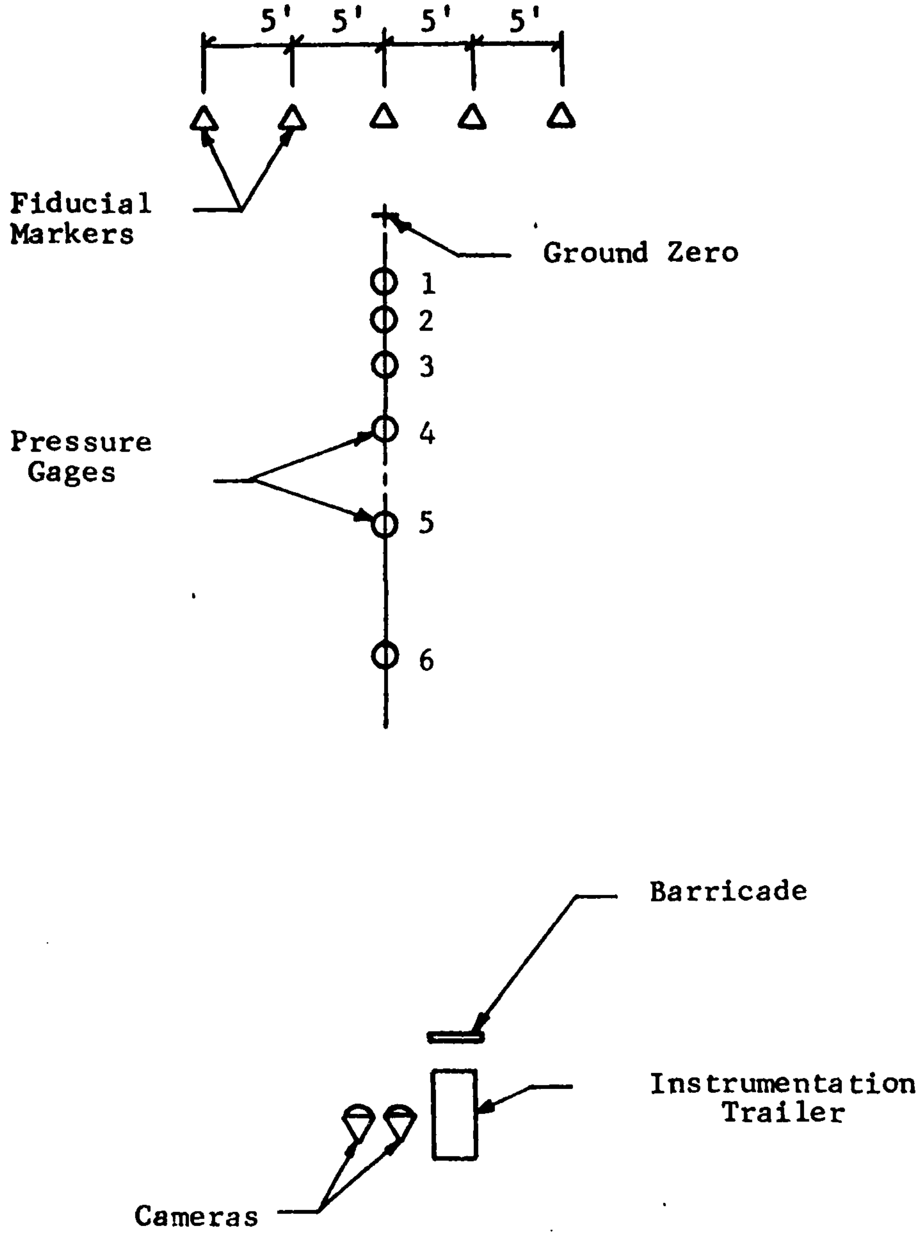


Figure 1 PLAN VIEW OF TEST AREA

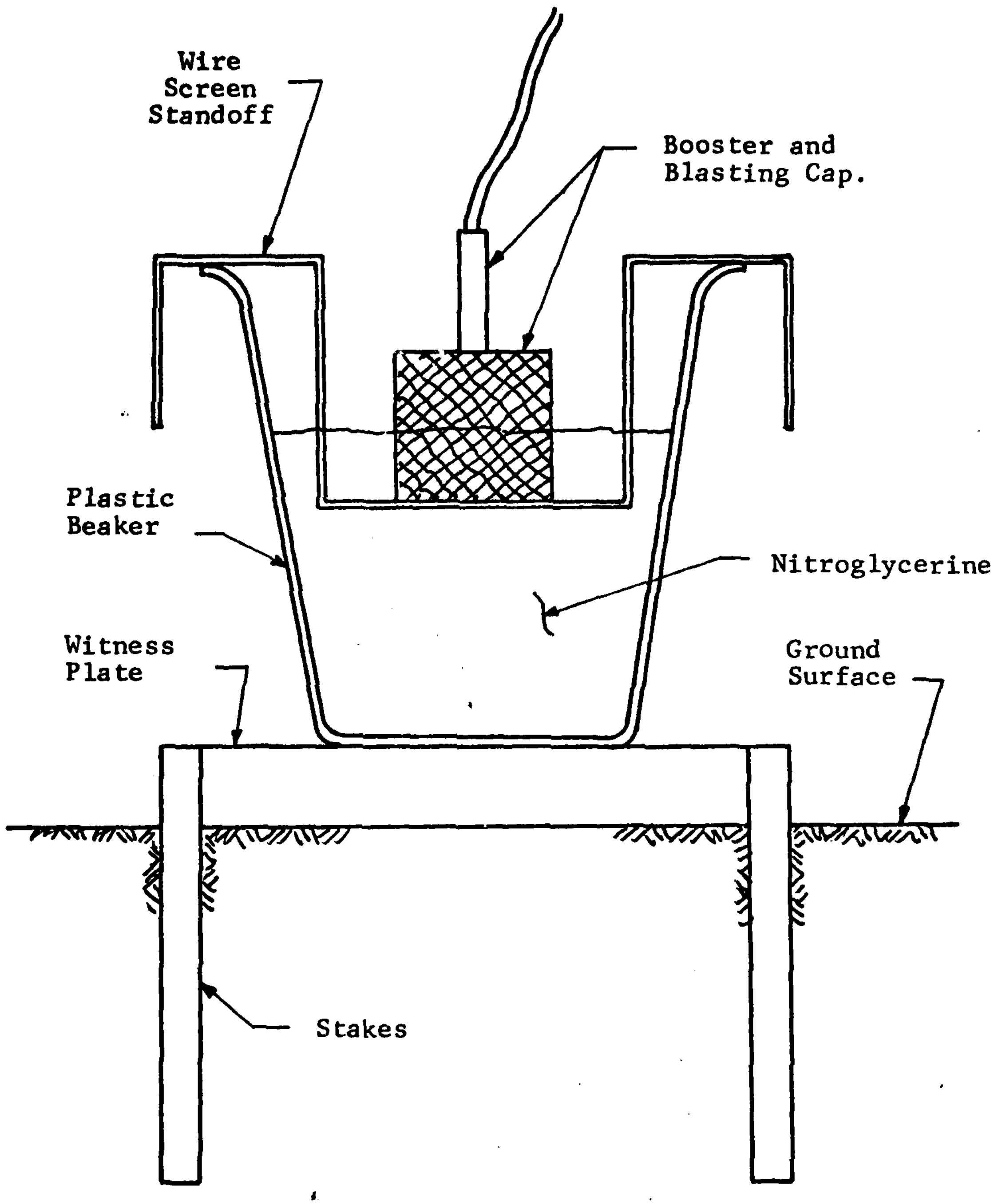


Figure 2 NITROGLYCERINE TEST CONFIGURATION

at ground zero, such that the bottom of the witness plate was flush with the ground surface. Nitroglycerine samples were placed in polymethylpentenc plastic laboratory beakers. The Nitroglycerine samples in the beakers were hand carried to the test site and placed on top of the witness plate as shown in the illustration. The beakers were sized, height and diameter, so that the Nitroglycerine samples would have an aspect ratio of approximately 1:1 when they were placed in the beakers. Copper wire screen was shaped, as shown in Figure 2, to fit in and over the beakers. This wire screen standoff was used to position the C4 boosters in the Nitroglycerine sample as shown. A ground strap wire was connected between the wire screen standoff and the steel witness plate.

A total of 27 tests were performed with Nitroglycerine samples that weighed approximately 1, 2, or 4 pounds. These values were chosen to provide a reasonable spread in charge weight and the maximum weight was limited by the safety requirements of the test facility. The samples were ignited with cylindrical C4 explosive boosters of various weights (the C4 boosters were ignited with number 6 electric blasting caps), number 6 electric blasting caps, hot wires, and attempts were made to ignite Nitroglycerine samples with DuPont S65 electric match squibs. The C4 boosters were wrapped in a plastic bag to prevent contamination of the Nitroglycerine samples.

Three calibration tests were performed to confirm the accuracy of the pressure measuring system. They consisted of detonating a bare hemisphere of C4 on a steel witness plate. The Output was measured and compared with previously established pressure-distance and impulse-distance curves fcr C4.

6. TEST RESULTS

This section contains results of the tests. Field data sheets pertinent to each test, measured overpressure and positive impulse, and computed TNT equivalency values are contained in the appendices of this report.

The Nitroglycerine experiments performed during this program are summarized in Table 1. The table includes test numbers, the measured weight of Nitroglycerine, type and size of the booster, and the result of each test.

Only three tests were conducted wherein no ignition of the Nitroglycerine sample occurred. In the first no-ignition test, Test 1-3, a DuPont S65 squib (electric match) was placed in a plastic bag and submerged in a Nitroglycerine sample. The squib appeared to have ignited and there was small hole in the plastic bag. In the second no-ignition test, Test 2-3, two S65 squibs were placed uncovered in the Nitroglycerine sample. Posttest examination of the squibs showed that the Nitroglycerine had reacted with the ignition mix on the squibs; it was soft and gummy to touch. An attempt to ignite the squibs after the test also failed. The third no-ignition test, Test 2-7, consisted of placing a bare resistance wire in a 2 pound Nitroglycerine sample. The wire was energized with 19.5 volts and 1.4 ohms of resistance. Posttest examination of this hot wire showed that the wire had burnt itself open and it was discolored from heat. It is interesting to note that a 1 pound sample of Nitroglycerine, Test 1-8, was ignited with a hot wire. After approximately 3 minutes of heating, 18 volts at 1.2 ohms, the 1 pound sample detonated. The 2 pound sample may have been too large in comparison to the amount of heat that was being supplied. However since Nitroglycerine is a poor heat conductor hotspot ignition appears more reasonable than elevating the temperature of the whole sample. More likely the hot wire used in the 2 pound sample was faulty and burned through before significant heat could be supplied to the sample.

Table 1 NITROGLYCERINE EXPERIMENTS

Test No.	Charge Weight	Booster	Result
1-1	0.95	9 gm C4	Detonation
1-2	1.22	23 gm C4	Detonation
1-3	≈1.00	S65 Squib	No Ignition
1-4	1.06	9 gm C4	Detonation
1-5	1.05	23 gm C4	Detonation
1-6	1.03	No. 6 Cap	Detonation
1-7	1.03	9 gm C4	Detonation
1-8	1.05	Hot Wire	Detonation
1-9	1.03	46 gm C4	Detonation
2-1	1.97	18 gm Cr	Detonation
2-2	1.97	45 gm C4	Detonation
2-3	≈2.00	2-S65 Squibs	No Ignition
2-4	2.00	18 gm C4	Detonation
2-5	1.97	45 gm C4	Detonation
2-6	1.98	No. 6 Cap	Detonation
2-7	≈2.00	Hot Wire	No Ignition
2-8	2.00	63 gm C4	Detonation
2-9	2.00	63 gm C4	Detonation
4-1	3.97	36 gm C4	Detonation
4-2	3.92	91 gm C4	Detonation
4-3	4.05	36 gm C4	Detonation
4-4	4.13	36 gm C4	Detonation
4-5	3.97	91 gm C4	Detonation
4-6	4.08	No. 6 Cap	Detonation
4-7	4.06	No. 6 Cap	Detonation
4-8	4.09	127 gm C4	Detonation
4-9	4.13	100 gm C4	Detonation
C-1	2.00	No. 6 Cap	Detonation
C-2	2.00	No. 6 Cap	Detonation
C-3	2.00	No. 6 Cap	Detonation

In all the tests where ignition of Nitroglycerine samples occurred no significant differences in scaled output were observed. Increasing or decreasing the booster size did not effect explosive output of the Nitroglycerine. The witness plates and fireball sizes indicate consistent output from a given charge weight. All the witness plates from the 1 pound charges had a small hole in their center and were bent downward underneath where the beaker was placed. All the witness plates from the 2 pound charges had a circular hole blown out of them that was approximately equal to the diameter of the beaker placed on top of them. Similarly all the witness plates from the 4 pound charges had circular holes about the same diameter as the 4 pound beakers. The remaining portion of the witness plates from the 4 pound tests were further cracked into several pieces. Posttest examination of the high speed films showed fireball diameters of approximately 4, 8, and 12 feet for charges weights of 1, 2, and 4 pounds respectively.

All of the pressure and impulse data accumulated on this program are tabulated and are plotted on graphs in Appendix B of this report. Scaled distances and scaled impulses have been corrected to account for the energy contribution of the boosters. The weights are based on total charge weight and therefore can be used directly when computing TNT equivalency. Each curve in Appendix B represents a single test and were obtained by mathematically curve fitting the data points from each individual test. After close examination of all the data it was determined that a single average curve for both peak pressure and scaled impulse should be obtained. All of the data points, after having been corrected for booster size, were put together and the following equations were computed.

Pressure

$$\log_{10}P = 4.367 - 4.313 (\log_{10}\lambda) + 0.195 (\log_{10}\lambda)^2,$$

Scaled Impulse

$$\log_{10}I/W^{1/3} = 2.148 - 1.445 (\log_{10}\lambda) + 0.192 (\log_{10}\lambda)^2,$$

where

P = Peak pressure, psig

λ = $R/W^{1/3}$ = scaled distance, ft/lb$^{1/3}$

R = Distance from charge, ft

W = Charge weight, lbs

I = Positive impulse, psi-msec.

These two equations are plotted on Figure 3 and represent the blast output from Nitroglycerine. The TNT equivalence of Nitroglycerine was computed using the averaged curves for peak pressure and scaled impulse. TNT equivalence is plotted on Figure 4. Note also that these curves should only be used in the scaled distance range in which tests were conducted, namely, 4 to 50 ft/lb$^{1/3}$. Extrapolation to other ranges may yield misleading results.

Three C4 calibration tests were performed and these results are plotted on Figure 5. The curves represent the blast output from hemispherical charges of TNT. The data points shown are the C4 calibration data measured during these tests. The independence of the TNT equivalency of Nitroglycerine based on peak pressure is illustrated in Figure 6. The horizontal lines give the constant equivalency at indicated scaled distances (λ's) based on all data. The circles indicate equivalencies obtained by averaging the data at individual charge weights. The numbers in parenthesis show the actual scaled distances for these data. The verticle bars measure the standard deviation within each weight class. It can readily be seen that variations within each class weight are as large as for all the data, hence there exists no dependence on charge weight. A similar conclusion can be reached from the impulse data.

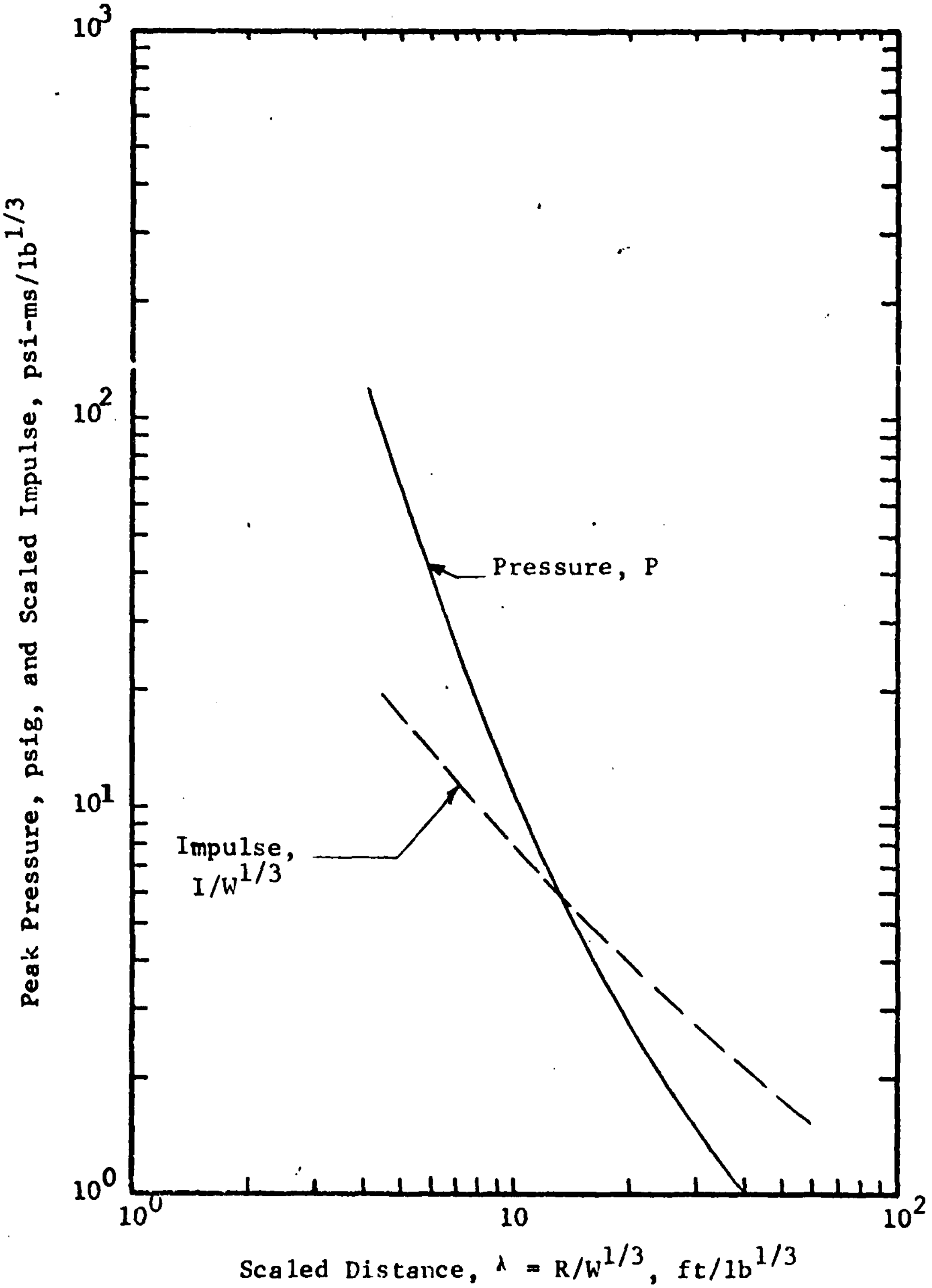


Figure 3 NITROGLYCERINE PRESSURE AND IMPULSE

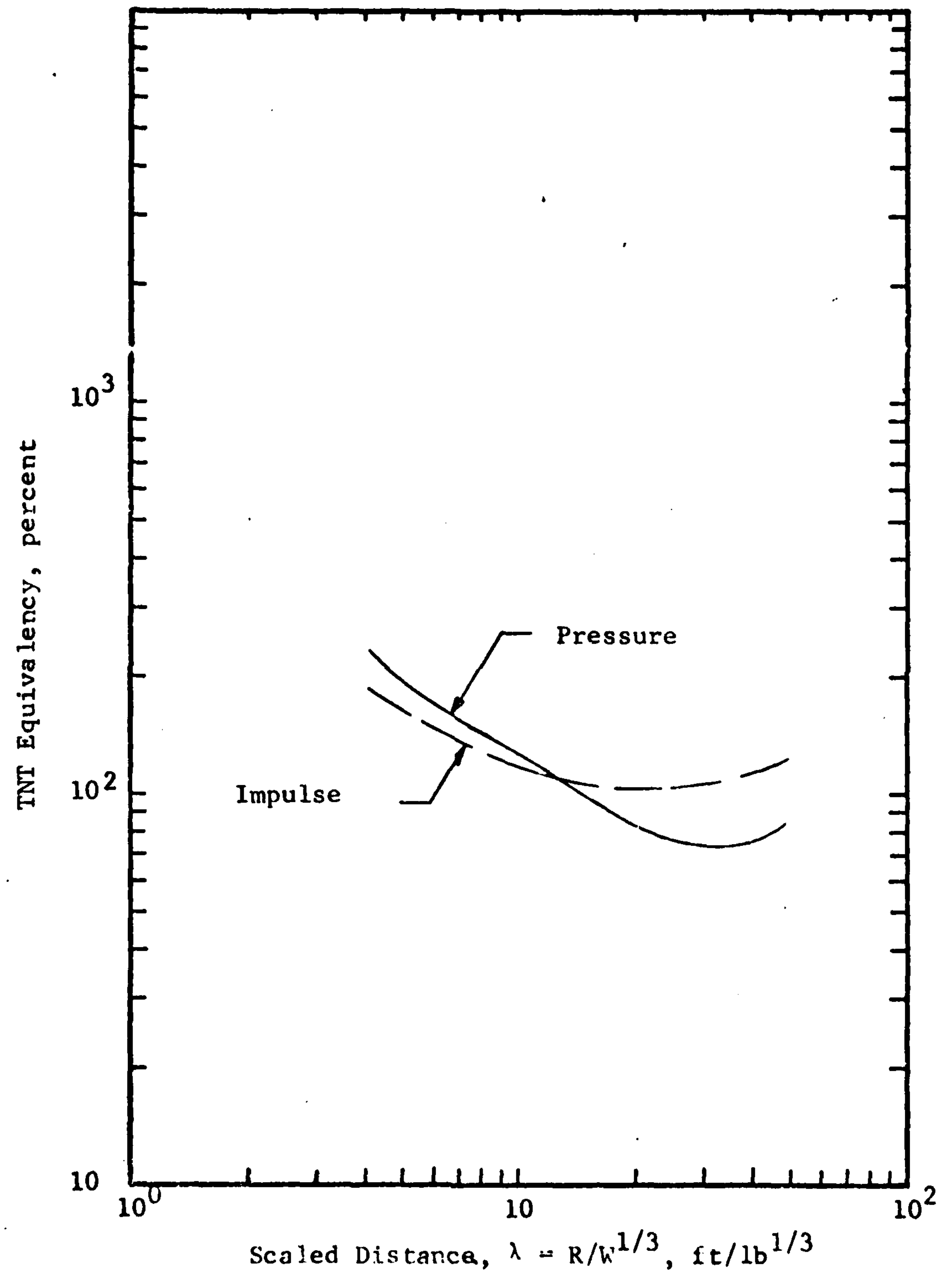


Figure 4 TNT EQUIVALENCE OF NITROGLYCERINE

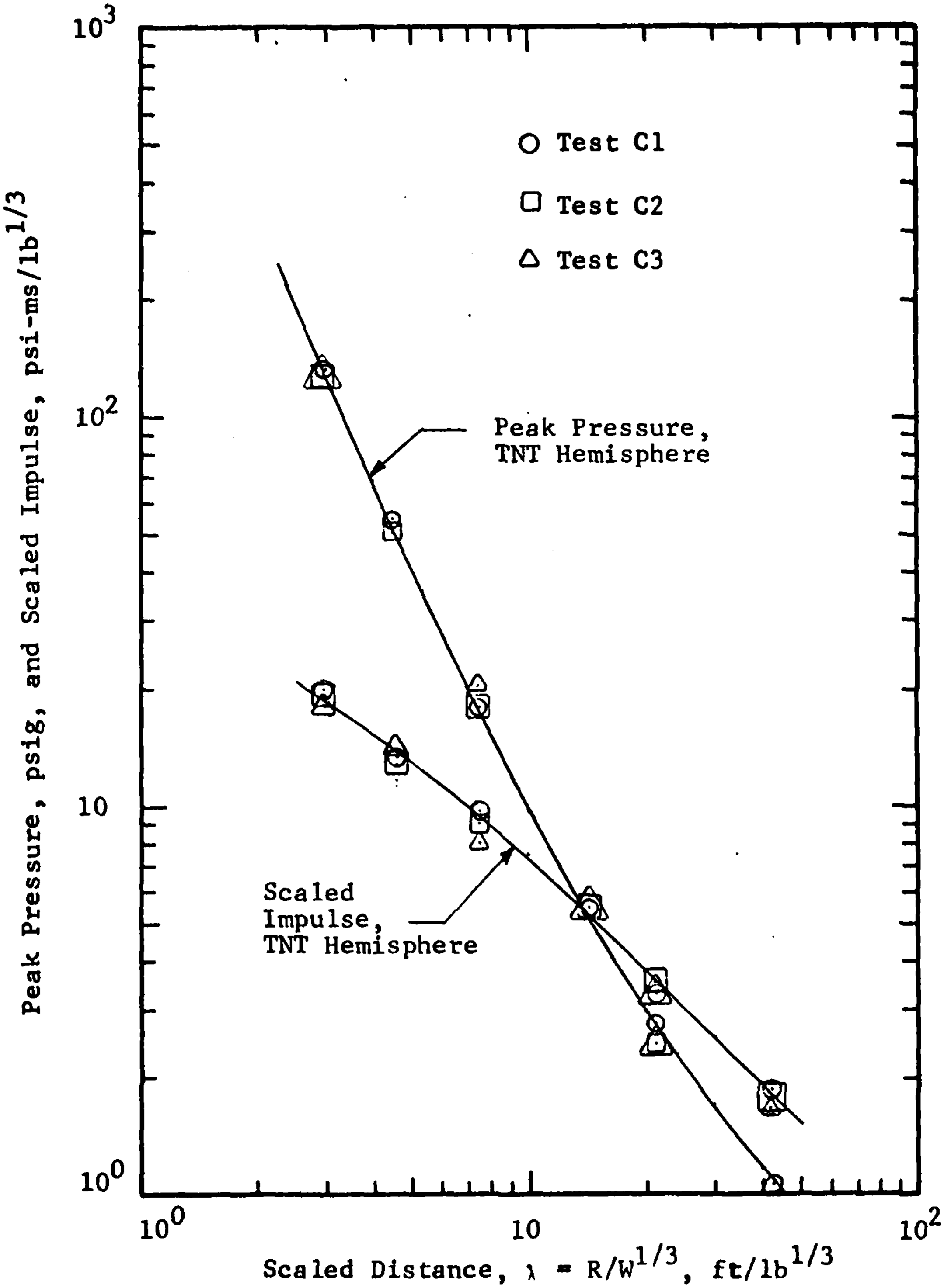


Figure 5 TNT PRESSURE AND IMPULSE

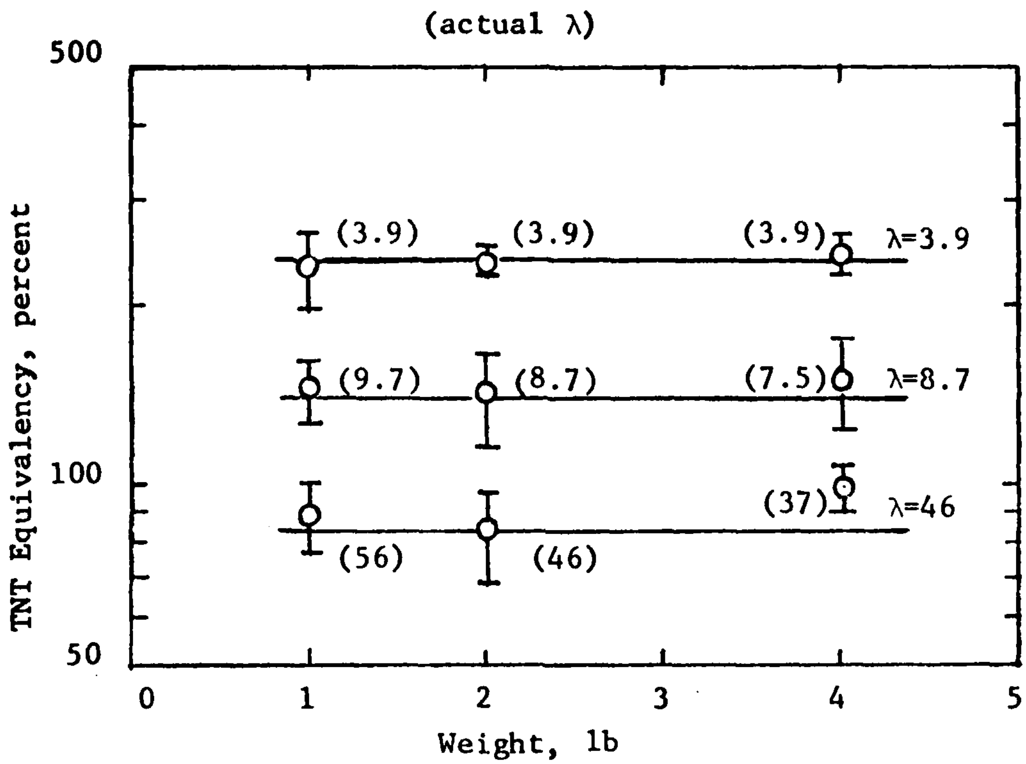


Figure 6 INFLUENCE OF CHARGE WEIGHT ON PRESSURE TNT EQUIVALENCE OF NITROGLYCERINE

APPENDIX A

FIELD DATA SHEETS

IITRI PROJECT NO. 16312 DATA SHEET NO. 1

TEST TITLE 1-1 DATE 7-6-73

TEST SAMPLE NITROGLYCERINE

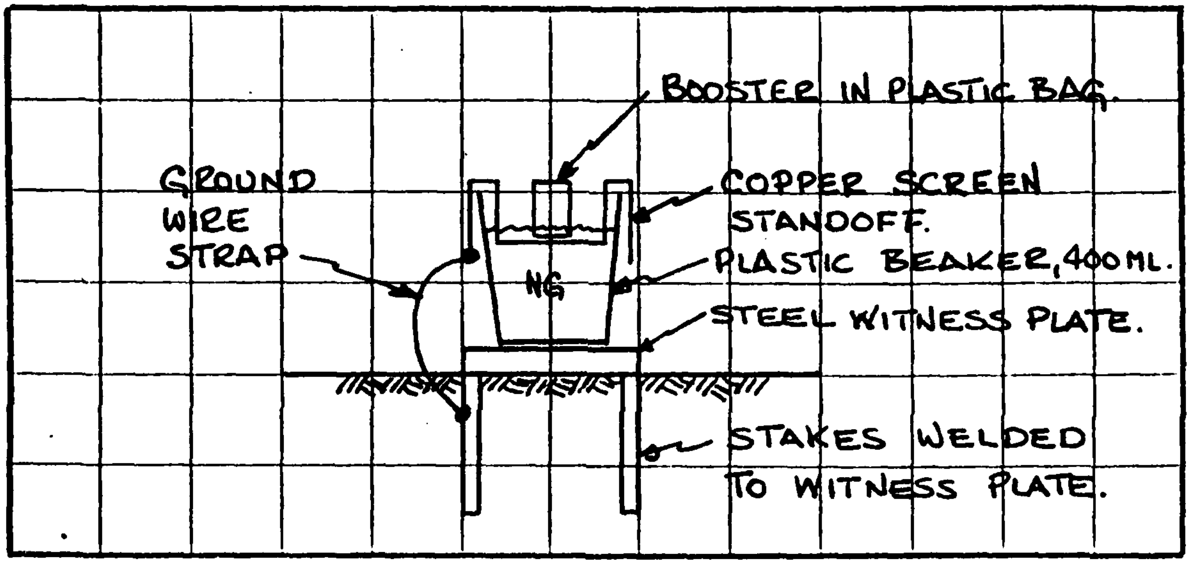
SAMPLE WEIGHT 15 1/4 oz

IGNITER NO. 6 ELECTRIC BLASTING CAP

BOOSTER 9.0 gm C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 4.0 feet FROM GAGE #1



FIELD EVALUATIONS:

NO FIREBRANDS SEEN BY OBSERVERS.

ROUND HOLE IN WITNESS PLATE ABOUT THE SAME DIAMETER AS BEAKER.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 2

TEST TITLE 1-2 DATE 7-6-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 1 LB-3½ oz

IGNITER NO. 6 ELECTRIC BLASTING CAP

BOOSTER 23 gm C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 4.0 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1-1

400ML BEAKER

FIELD EVALUATIONS:

ROUND HOLE IN WITNESS PLATE ABOUT THE SAME DIAMETER AS BEAKER.

TEST ENGINEER: J SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 3

TEST TITLE 1.3 DATE 7-6-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT ≈ 1 LB.

IGNITER S65 DUPONT SQUIB

BOOSTER NONE

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 4.0 feet FROM GAGE #1

SAME CONFIGURATION AS 1-1.

NOT USING COPPER SCREEN STANDOFF

400 ML BEAKER

FIELD EVALUATIONS:

NO IGNITION OF NG.

THE SQUIB IGNITED AND BURNED A HOLE IN THE PLASTIC BAG.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 4

TEST TITLE 1.4 DATE 7-11-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 1 LB - 1 OZ

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER 9 GM C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 401 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1.1

400 ML BEAKER.

FIELD EVALUATIONS:

ROUND HOLE IN WITNESS PLATE ABOUT THE SAME DIAMETER AS BEAKER.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. 16312

DATA SHEET NO. 5

TEST TITLE 1-5

DATE 7-11-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 1 LB - 3/4 OZ

IGNITER NO. 6 ELECTRIC BLASTING CAP

BOOSTER 23 GM C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 4.02 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1-1

400 ML BEAKER

FIELD EVALUATIONS:

ROUND HOLE IN WITNESS PLATE ABOUT THE SAME DIAMETER AS BEAKER.

TEST ENGINEER J. SWATOSH

IITRI PROJECT NO. 16312 DATA SHEET NO. 6

TEST TITLE 1-6 DATE 7-11-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 1 LB - 1/2 OZ

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER —

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 4.02 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1-1

NO STANDOFF

CAP IN APPROXIMATE MIDDLE OF SAMPLE.

400 ML BEAKER

FIELD EVALUATIONS:

WITNESS PLATE BENT AND CRACKED.

TEST ENGINEER: J SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 7

TEST TITLE 1-7 DATE 7-11-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 1 LB - 1/2 OZ

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER 9 GM C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 4.02 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1-1.

400 ML BEAKER.

FIELD EVALUATIONS:

WITNESS PLATE BENT AND CRACKED.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. J6312

DATA SHEET NO. 8

TEST TITLE 1-8

DATE 7-12-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 1 LB - 3/4 OZ

IGNITER HOT WIRE - 1.2 OHMS, 18 VOLTS

BOOSTER NONE

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 4.00 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1-1.
NO STANDOFF.
400 ML BEAKER.

FIELD EVALUATIONS: THREE MINUTES AFTER START OF HEAT IT DETONATED.

WITNESS PLATE BENT AND CRACKED SAME AS PREVIOUS 1# TESTS

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 9

TEST TITLE 1.9 DATE 7.12.73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 1 LB - 1/2 OZ

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER 46 gm C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 4.02 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1.1

400 ML BEAKER.

FIELD EVALUATIONS:

WITNESS PLATE BENT AND CRACKED

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 10

TEST TITLE 2-1 DATE 7-6-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 1 LB - 15½ OZ

IGNITER NO. 6 ELECTRIC BLASTING CAP

BOOSTER 18 gm C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 5.06 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1.1

600 ML BEAKER

FIELD EVALUATIONS:

ROUND HOLE IN WITNESS PLATE ABOUT THE SAME SIZE AS BEAKER.

TEST ENGINEER J. SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 11

TEST TITLE 2-2 DATE 7-9-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 1 LB - 15 1/2 OZ

IGNITER NO. 6 ELECTRIC BLASTING CAP

BOOSTER 45 GM C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 5.03 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1.1

600 ML BEAKER

FIELD EVALUATIONS:

ROUND HOLE IN WITNESS PLATE ABOUT THE SAME DIAMETER AS BEAKER.

TEST ENGINEER: J SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 12

TEST TITLE 2.3 DATE 7-9-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT ≈ 2 LBS

IGNITER 2- S65 DUPONT SQUIBS

BOOSTER —

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 5.02 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1.1

NO COPPER SCREEN STANDOFF.

NO PLASTIC BAG ON SQUIBS.

600 ML BEAKER.

FIELD EVALUATIONS:

THE NITROGLYCERIN DID NOT IGNITE.

THE NG REACTED WITH THE IGNITION MIX ON THE SQUIB, THE MIX WAS SOFT TO TOUCH AND WAS NOT BURNT.

A SECOND ATTEMPT TO IGNITE THE SQUIBS IN WATER ALSO FAILED.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 13

TEST TITLE 2-4 DATE 7-11-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 2 LBS -

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER 18 gm C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 5.04 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1-1.

600 ML BEAKER.

FIELD EVALUATIONS:

HOLE IN WITNESS PLATE ABOUT THE SAME DIAMETER AS BEAKER.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. J6312

DATA SHEET NO. 14

TEST TITLE 2-5

DATE 7-11-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 1 LB - 15½ OZ

IGNITER No.6 ELECTRIC BLASTING CAP

BOOSTER 45 Gm C4

FASTEX CAMERA (1000 cps) ☒

BOLEX (32 fps) ☒

CHARGE LOCATED 5.07 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1-1.

600 ML BEAKER.

FIELD EVALUATIONS:

HOLE IN WITNESS PLATE SAME DIAMETER AS BEAKER.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. 16312 DATA SHEET NO. 15

TEST TITLE 2-6 DATE 7-11-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 1 LB - 15 3/4 OZ.

IGNITER No. 6 ELECTRIC BLASTING CAP.

BOOSTER NONE

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 4.98 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1-1.

NO STANDOFF USED.

600 ML BEAKER.

FIELD EVALUATIONS:

HOLE IN WITNESS PLATE ABOUT THE SAME DIAMETER AS BEAKER.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 16

TEST TITLE 2.7 DATE 7-12-73

TEST SAMPLE NITROGLYCERIN

SAMPLE WEIGHT ≈ 2 LBS

IGNITER HOT WIRE - 1.4 OHMS, 19.5 VOLTS

BOOSTER NONE

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 5.00 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1.1

600 ML BEAKER.

FIELD EVALUATIONS:

HEATER ON FOR 15½ MIN. "NO REACTION."

THE NG SHOWED NO SIGNS OF DECOMPOSITION.

THE HOT WIRE WAS DISCOLORED AND BURNT THROUGH.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 17

TEST TITLE 2-8 DATE 7-12-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 2 LBS -

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER 63 GM C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 3.00 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1-1.

600 ML BEAKER.

FIELD EVALUATIONS:

WITNESS PLATE CRACKED IN HALF. HOLE ABOUT THE DIAMETER OF THE BEAKER.

 TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 18

TEST TITLE 2-9 DATE 7-12-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 2 LBS -

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER 63 gm C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 5.06 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1-1

600 ML BEAKER

FIELD EVALUATIONS:

WITNESS PLATE BROKEN. TYPICAL 2# SHOT

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. 16312 DATA SHEET NO. 19

TEST TITLE 4-1 DATE 7-10-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 3 LBS - 15 1/2 OZ

IGNITER NO. 6 ELECTRIC BLASTING CAP

BOOSTER 36 Gm C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 6.03 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1.1

2000 ML BEAKER.

FIELD EVALUATIONS:

WITNESS PLATE BROKEN INTO FIVE PIECES.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 20

TEST TITLE 4.2 DATE 7-10-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 3 LBS - 14 3/4 OZ

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER 91 gm C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 6.03 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1.1

2000 ML BEAKER

FIELD EVALUATIONS:

MISS FIRE → OPEN FIRING LINE - CORRECTION MADE AND SAME SHOT REFIRED.

WITNESS PLATE BROKE IN TWO PIECES. HOLE IN CENTER ABOUT SAME SIZE AS BEAKER DIAMETER.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 21

TEST TITLE 4.3 DATE 7-10-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 4 LBS - 3/4 OZ

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER 36 Gm C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 6.03 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1.1.

2000 ML BEAKER.

FIELD EVALUATIONS:

WITNESS PLATE BROKE IN HALF, HOLE IN CENTER ABOUT SAME SIZE AS BEAKER DIAMETER.

TEST ENGINEER J. SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 22

TEST TITLE 4.4 DATE 7-11-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 4 LB. 2 OZ

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER 36 Gm C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 6.03 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1.1.
2000 ML BEAKER.

FIELD EVALUATIONS:

WITNESS PLATE BROKE, CIRCULAR PIECE FROM CENTER ABOUT SAME SIZE AS BEAKER

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. K6312 DATA SHEET NO. 23

TEST TITLE 4-5 DATE 7.11.73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 3 LBS - 15½ OZ

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER 91 GM C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 5.99 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1.1.
2000 ML BEAKER.

FIELD EVALUATIONS:

WITNESS PLATE BROKE, HOLE IN WITNESS PLATE ABOUT THE SAME DIAMETER AS BEAKER.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. 16312 DATA SHEET NO. 24

TEST TITLE 4-6 DATE 7.11.73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 4 LBS - 1 1/4 OZ.

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER NONE

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 6.00 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1-1

NO STANDOFF.

2000 ML BEAKER.

FIELD EVALUATIONS:

WITNESS PLATE BROKE, SPALLED, ROUND PIECE ABOUT THE DIAMETER OF BEAKER.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 25

TEST TITLE 4-7 DATE 7-12-73

TEST SAMPLE NITROGLYCERINE

SAMPLE WEIGHT 4 LBS 1 OZ

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER NONE

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 6.00 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1-1.

NO SCREEN WIRE STANDOFF

2000 ML BEAKER

FIELD EVALUATIONS:

WITNESS PLATE BROKEN. HOLE ABOUT THE SAME DIAMETER AS BEAKER.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. 16312 DATA SHEET NO. 26

TEST TITLE 4-8 DATE 7-13-73

TEST SAMPLE NITROGLYCERIN

SAMPLE WEIGHT 4 LBS - 1½ oz.

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER 127 Gm C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 596 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1-1.
2000 ML BEAKER.

FIELD EVALUATIONS:

WITNESS PLATE BROKEN, TYPICAL 4# RESULT.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. 16312 DATA SHEET NO. 27

TEST TITLE 4-9 DATE 7.13.73

TEST SAMPLE NITROGLYCERIN

SAMPLE WEIGHT 4 LBS- 2 OZ

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER 100 Gm C4

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 6.00 feet FROM GAGE #1

SAME TEST CONFIGURATION AS 1-1.
2000 ML BEAKER.

FIELD EVALUATIONS:

WITNESS PLATE BROKEN, TYPICAL 4# SHOT.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. J6312 DATA SHEET NO. 28

TEST TITLE C-1 DATE 7.5.73

TEST SAMPLE C4 HEMISPHERE

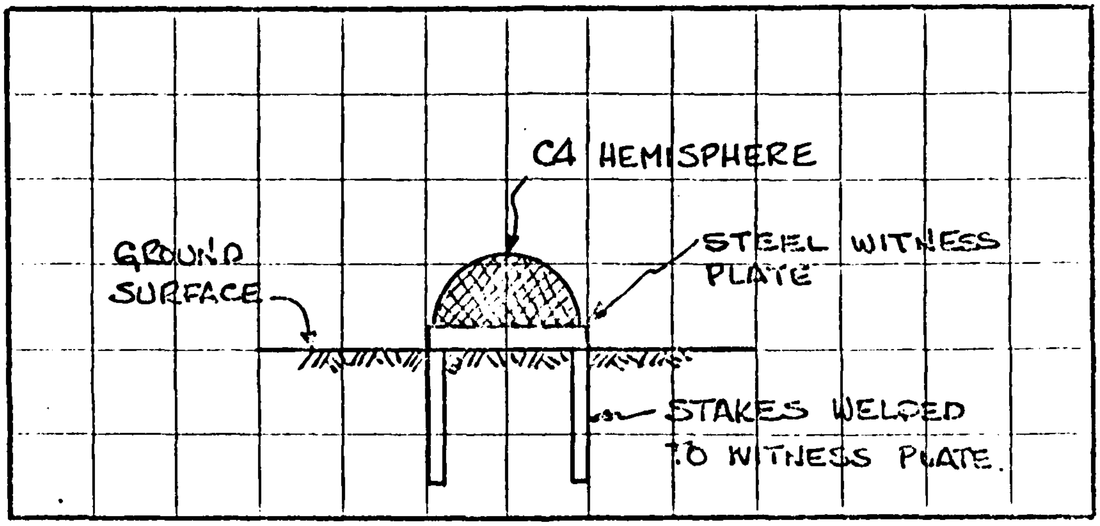
SAMPLE WEIGHT 2.0 LBS.

IGNITER NO. 6 ELECTRIC BLASTING CAP

BOOSTER

FASTEX CAMERA (1000 cps) ☒ BOLEX (32 fps) ☒

CHARGE LOCATED 4.0 feet FROM GAGE #1



FIELD EVALUATIONS:

TYPICAL CALIBRATION SHOT.

WITNESS PLATE BURIED IN GROUND, CRACKED INTO THREE PIECES, SPALLED, ONE OF THE PIECES WAS ROUND- ABOUT THE SAME DIAMETER AS THE C4 CHARGE.

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. J6312

DATA SHEET NO. 29

TEST TITLE C2

DATE 7-11-73

TEST SAMPLE C4 HEMISPHERE

SAMPLE WEIGHT 2.0 LBS

IGNITER NO. 6 ELECTRIC BLASTING CAP

BOOSTER

FASTEX CAMERA (1000 cps) ☐   BOLEX (32 fps) ☐

CHARGE LOCATED 4.02 feet FROM GAGE #1

SAME TEST CONFIGURATION AS C1

FIELD EVALUATIONS:

TYPICAL CALIBRATION SHOT.

WITNESS PLATE BROKEN INTO THREE PIECES, ROUND CENTER PIECE ABOUT THE SAME DIAMETER AS THE CHARGE

TEST ENGINEER: J. SWATOSH

IITRI PROJECT NO. 16312

DATA SHEET NO. 30

TEST TITLE C-3

DATE 7-13-73

TEST SAMPLE C4 HEMISPHERE

SAMPLE WEIGHT 2.0 LBS.

IGNITER No. 6 ELECTRIC BLASTING CAP

BOOSTER

FASTEX CAMERA (1000 cps) [X]

BOLEX (32 fps) [X]

CHARGE LOCATED 3.98 feet FROM GAGE #1

SAME TEST CONFIGURATION AS C1

FIELD EVALUATIONS:

TYPICAL CALIBRATION SHOT.

WITNESS PLATE SPALLED, BROKEN.

TEST ENGINEER: J Swatosh

APPENDIX B

TEST DATA

AND

TNT EQUIVALENCY CALCULATIONS

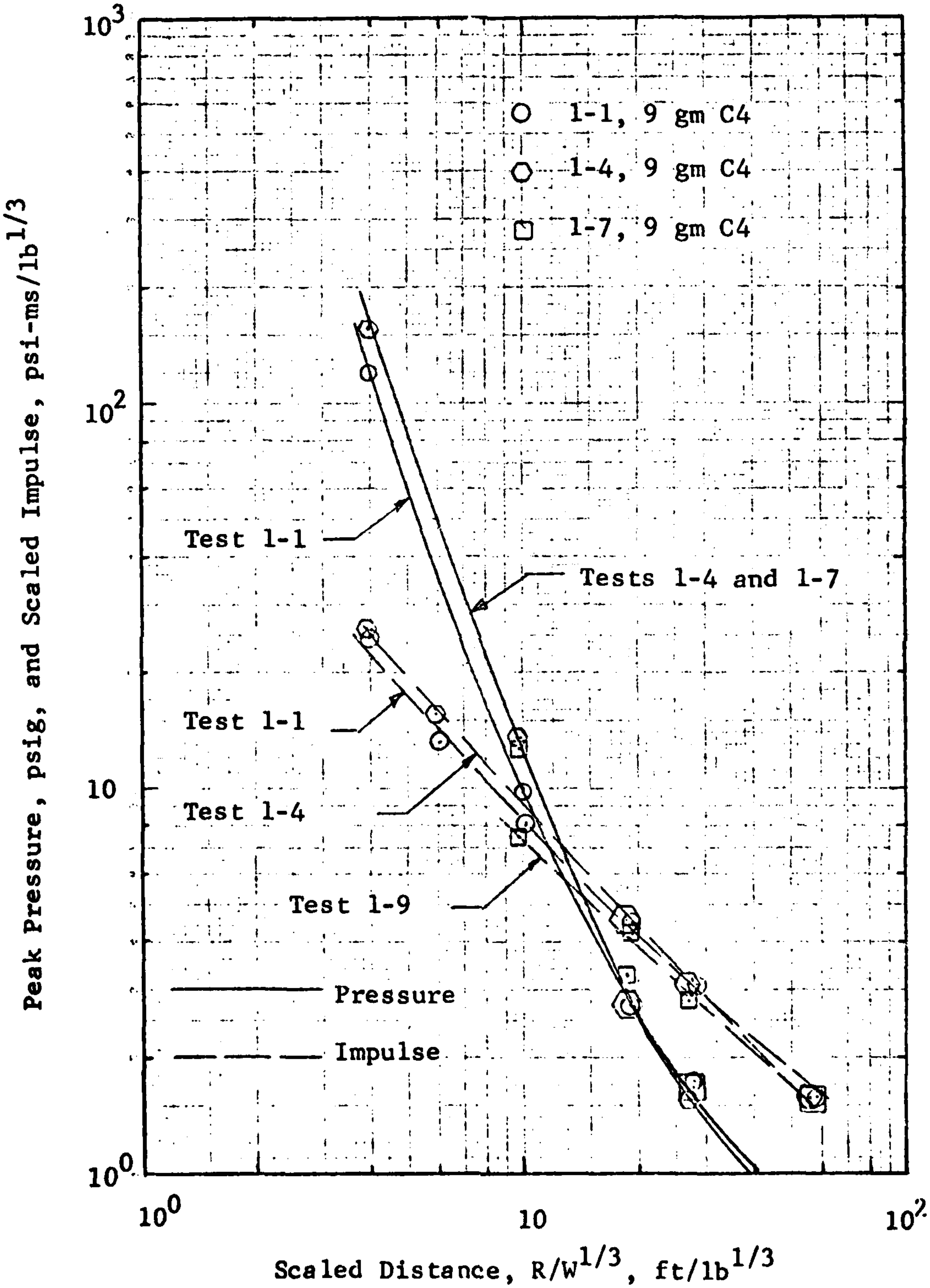


Figure B1, PRESSURE, TESTS 1-1, 1-4, 1-7

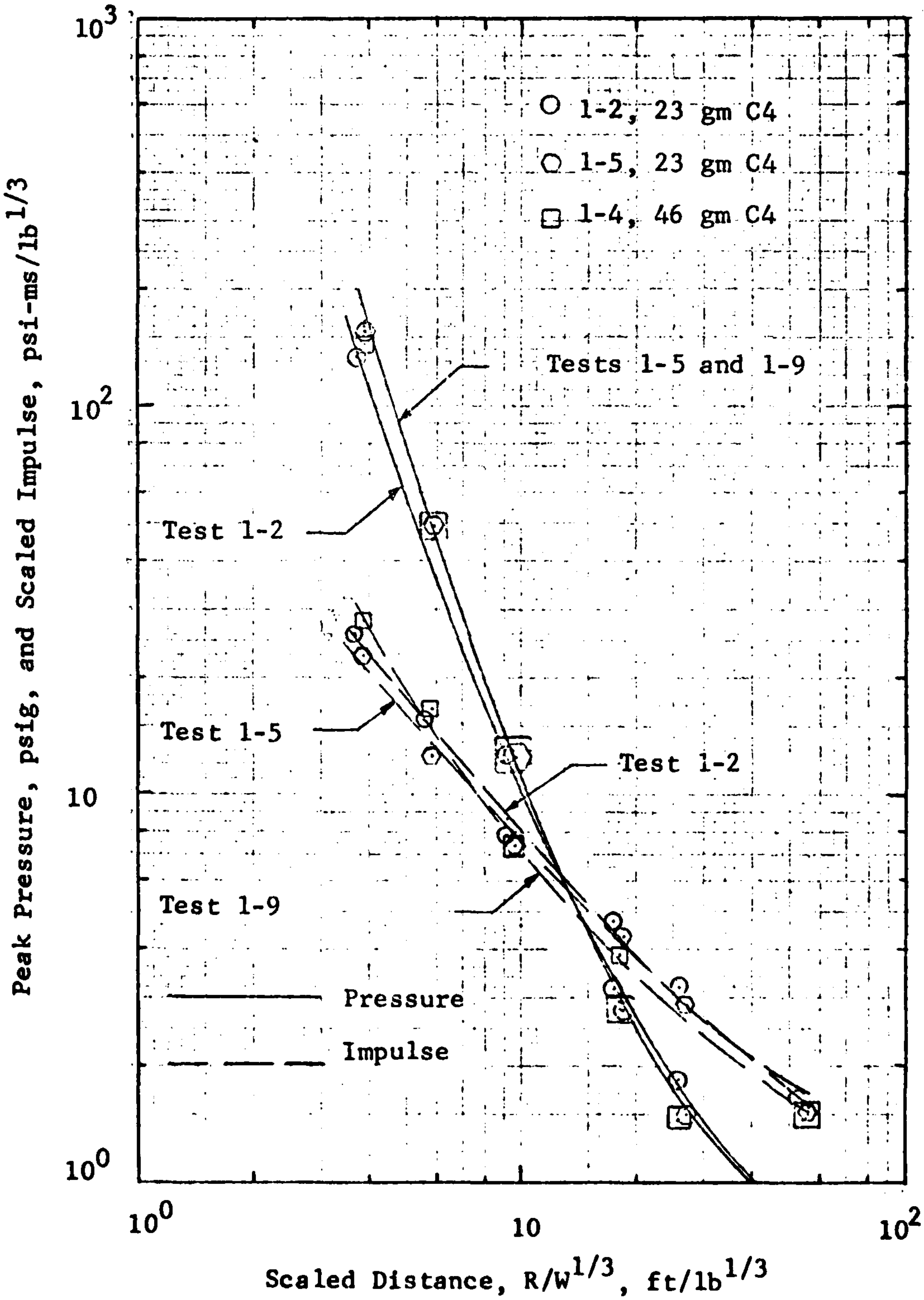


Figure B2, PRESSURE, TESTS 1-2, 1-5, 1-9

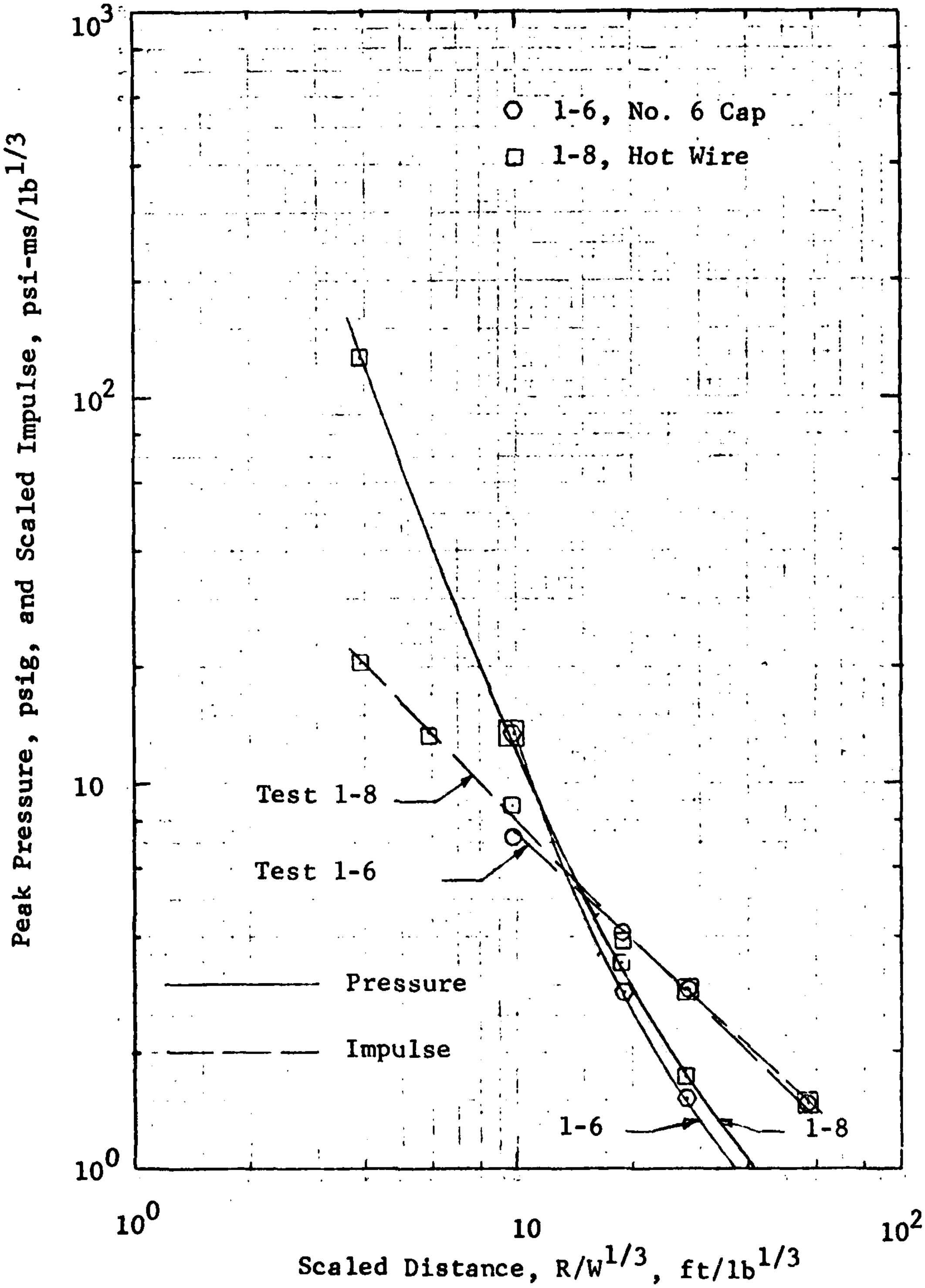


Figure B3, PRESSURE, TESTS 1-6, 1-8

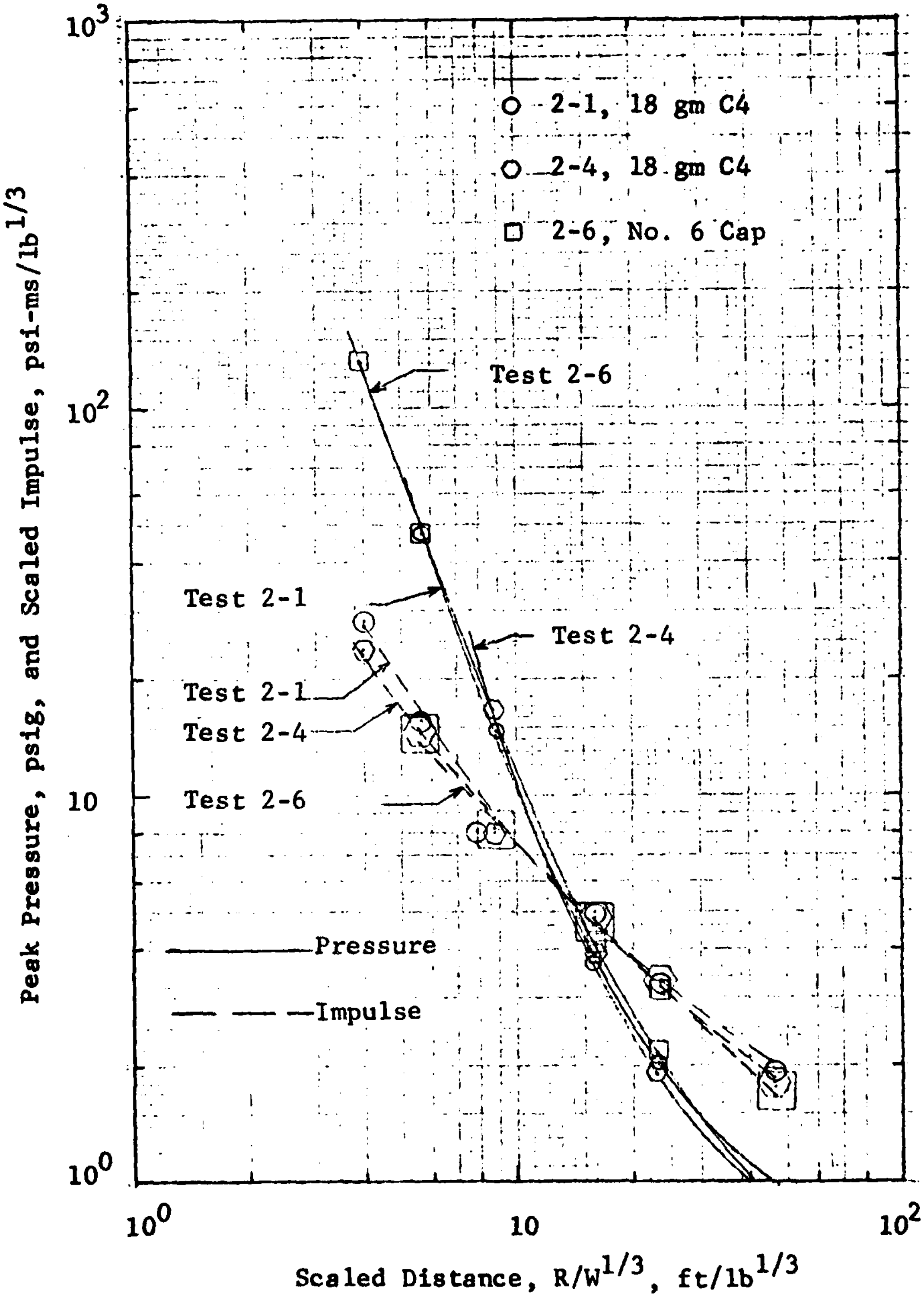


Figure B4, PRESSURE, TESTS 2-1, 2-4, 2-6

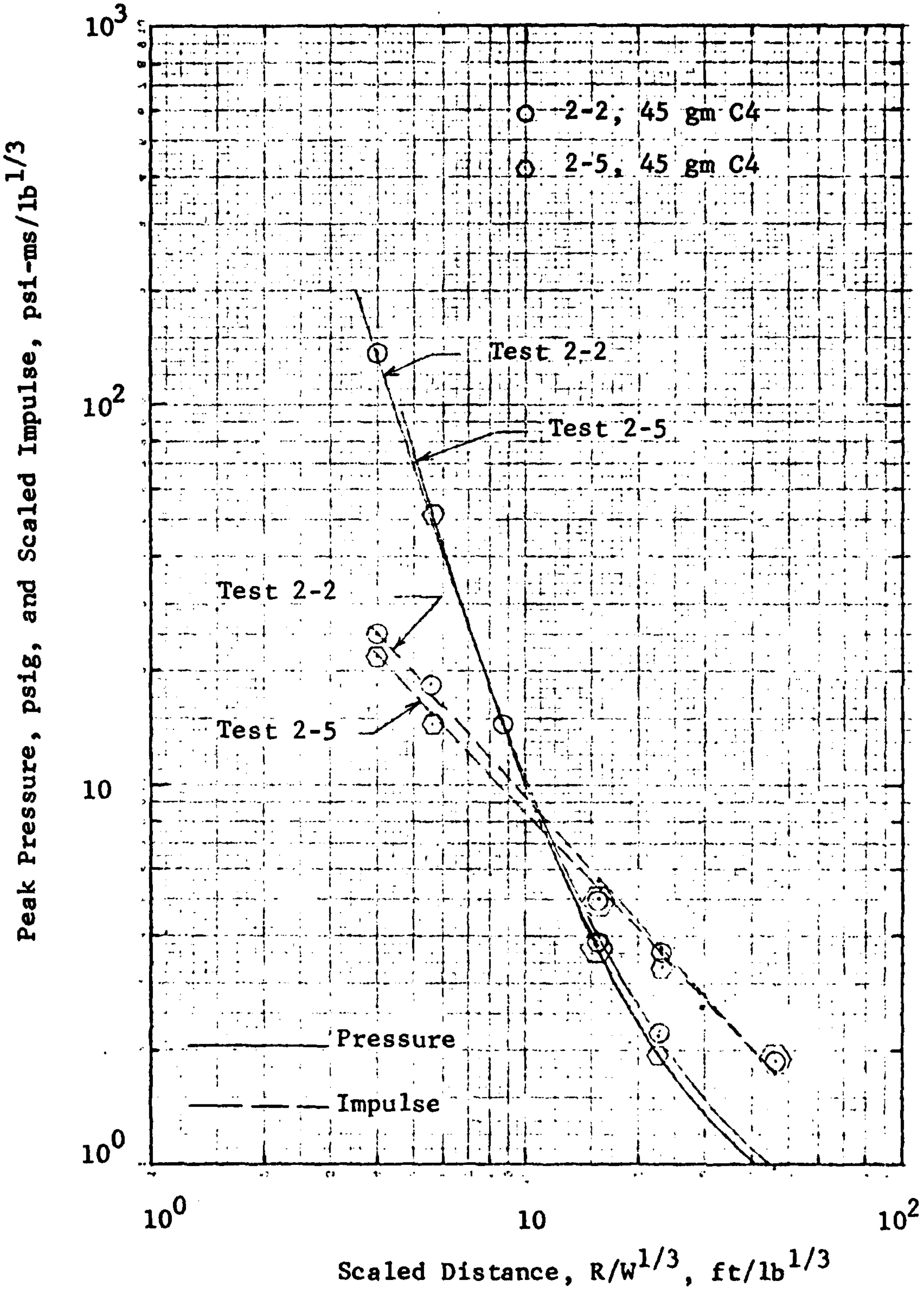


Figure B5, PRESSURE, TESTS 2-2, 2-5

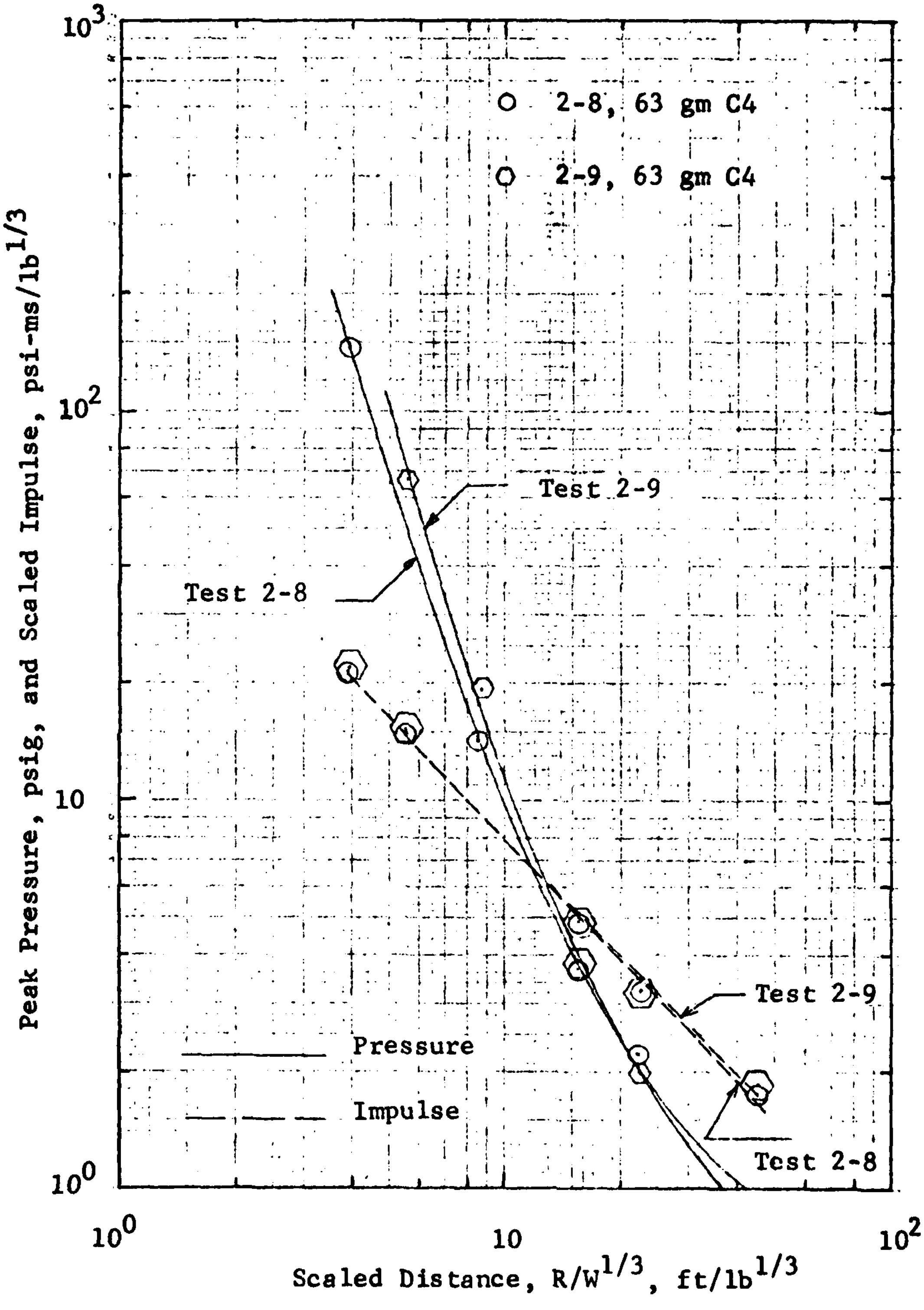


Figure B6, PRESSURE, TESTS 2-8, 2-9

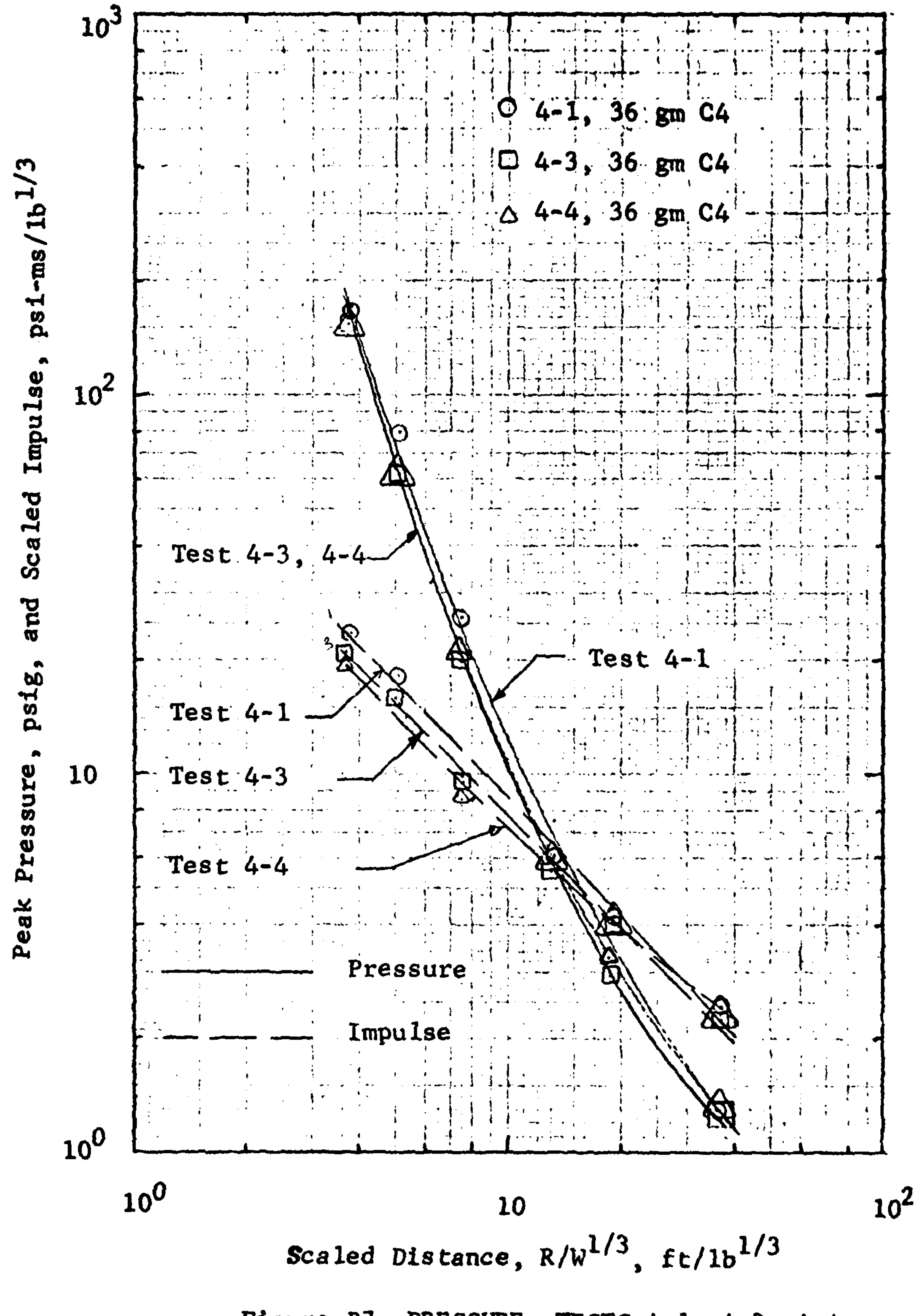


Figure B7, PRESSURE, TESTS 4-1, 4-3, 4-4

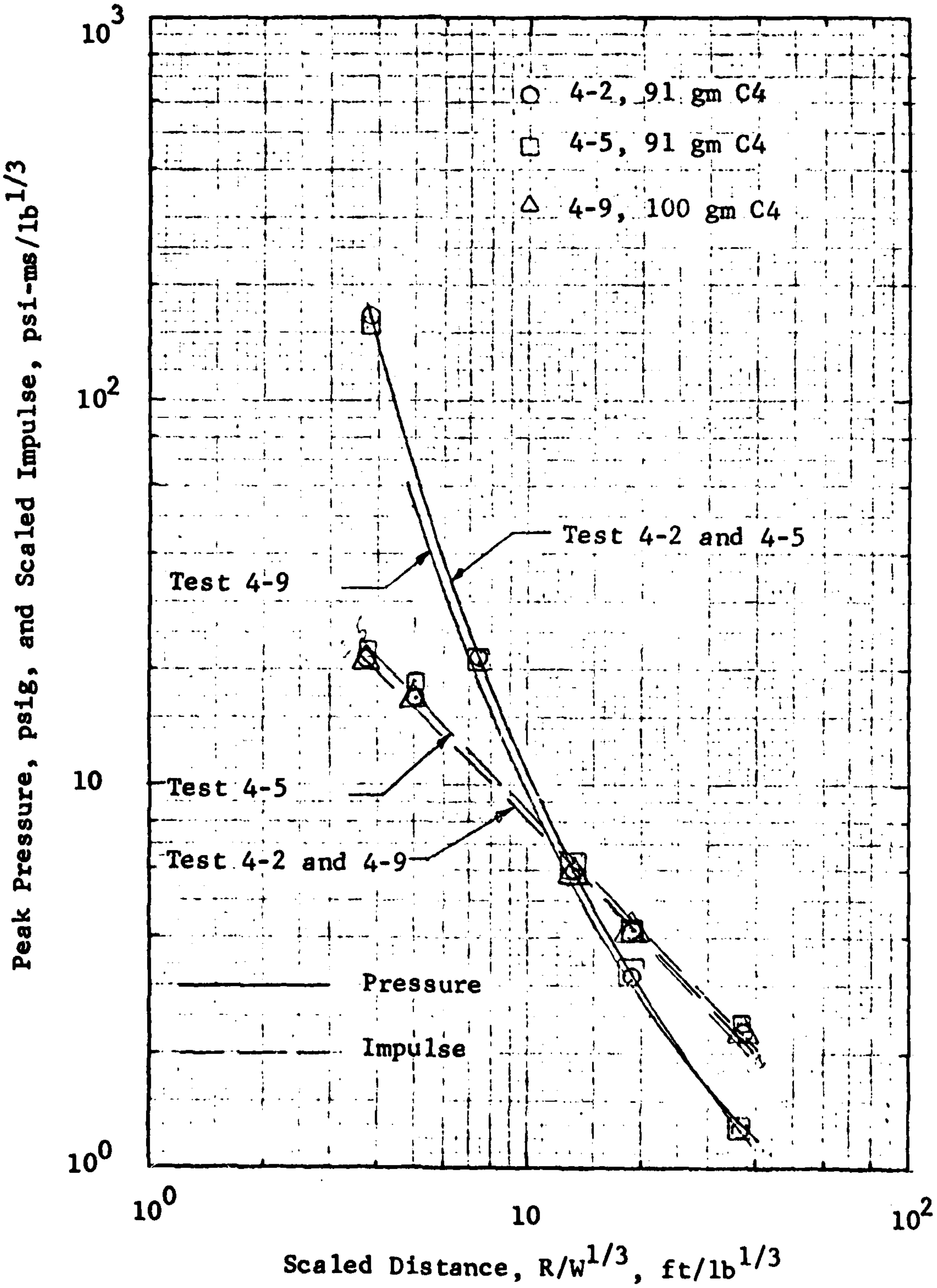


Figure B8, PRESSURE, TESTS 4-2, 4-5, 4-9

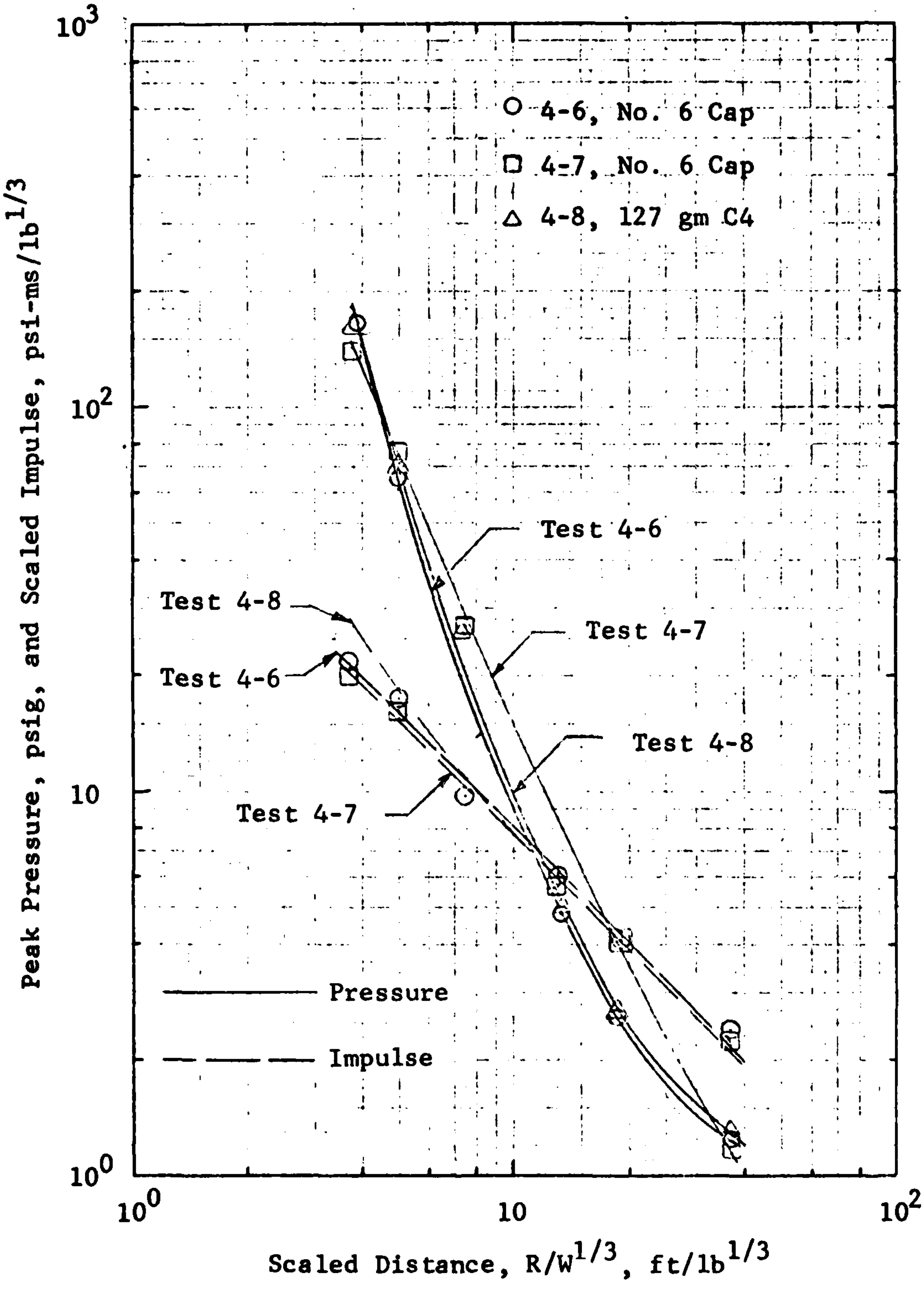


Figure B9, PRESSURE, TESTS 4-6, 4-7, 4-8

AVERAGE CURVE

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ ($PSI\text{-}MS/LB^{1/3}$)	LAMBDA-P ($FT/LB^{1/3}$)	LAMBDA-I ($FT/LB^{1/3}$)	EQ-P (%)	EQ-I (%)
AVERAGE CURVE							
	-	135.20	22.27	4.00	4.00	238.65	188.05
	-	68.96	17.06	5.00	5.00	190.64	161.87
	-	27.10	11.59	7.00	7.00	154.22	135.02
	-	11.20	7.85	10.00	10.00	128.33	117.83
	-	4.69	5.18	15.00	15.00	99.98	107.83
	-	2.76	3.92	20.00	20.00	83.47	105.45
	-	1.03	2.12	40.00	40.00	73.72	113.85
	-	.82	1.76	50.00	50.00	83.79	121.12

SUMMARY OF EXPERIMENTAL RESULTS

CURVE FIT

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ ($PSI-MS/LB^{1/3}$)	LAMBDA-P ($FT/LB^{1/3}$)	LAMBDA-I ($FT/LB^{1/3}$)	EQ-P (%)	EQ-I (%)
1-1 .953 LB NG 9 G C4							
	4.00	118.38	23.28	4.05	4.05	206.68	205.72
	6.05	- -	14.30	- -	6.12	- -	158.62
	9.99	10.16	8.23	10.08	10.09	112.94	128.50
	19.10	2.83	4.28	19.20	19.27	78.14	114.66
	28.20	1.58	2.98	28.31	28.45	70.76	116.01
	57.70	.78	1.64	58.21	58.27	116.93	137.12
1-2 1.219 LB NG. 23 G C4							
	4.00	134.03	25.65	3.71	3.72	188.37	216.66
	6.05	- -	15.46	- -	5.60	- -	160.25
	9.99	12.13	8.73	9.21	9.23	113.21	124.94
	19.10	3.33	4.48	17.52	17.60	82.62	108.11
	28.20	1.81	3.12	25.80	25.99	72.23	108.49
	57.70	.81	1.72	53.09	53.31	97.51	128.69

SUMMARY OF EXPERIMENTAL RESULTS

CURVE FIT

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ ($PSI-MS/LB^{1/3}$)	LAMBDA-P ($FT/LB^{1/3}$)	LAMBDA-I ($FT/LB^{1/3}$)	EQ-P (%)	EQ-I (%)
1-4	1.063 LB NG, 9 G C4						
	4.01	160.14	24.77	3.92	3.92	282.73	218.67
	6.06	- -	16.04	- -	5.91	- -	183.12
	10.00	11.93	- -	9.74	- -	130.61	- -
	19.10	3.01	4.80	18.54	18.61	79.86	130.26
	28.20	1.58	3.18	27.30	27.46	63.69	121.58
	57.70	.70	1.50	56.02	56.16	81.00	113.27
1-5	1.047 LB NG, 23 G C4						
	4.02	166.34	21.53	3.93	3.91	301.33	172.53
	6.07	45.55	13.43	5.91	5.89	184.01	135.90
	10.00	11.85	7.63	9.70	9.68	127.50	111.97
	19.10	2.97	4.10	18.33	18.45	75.16	100.91
	28.30	1.57	2.86	27.00	27.34	60.31	102.26
	57.70	.72	1.57	55.56	55.90	86.12	120.04
1-6	1.031 LB NG, NO BOOSTER						
	10.00	13.49	7.43	9.90	9.90	164.61	106.35
	19.10	2.90	4.12	18.91	18.91	78.52	105.05
	28.30	1.46	2.87	28.01	28.01	57.39	107.06
	57.70	.68	1.50	57.12	57.12	80.37	116.17

SUMMARY OF EXPERIMENTAL RESULTS

CURVE FIT

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ ($PSI-MS/LB^{1/3}$)	LAMBDA-P ($FT/LB^{1/3}$)	LAMBDA-I ($FT/LB^{1/3}$)	EQ-P (%)	EQ-I (%)
1-7 1.031 LB NG, 9 G C4							
	10.00	12.95	7.49	9.85	9.83	152.50	106.70
	19.10	3.30	4.17	18.76	18.77	99.57	106.10
	28.30	1.69	2.92	27.74	27.81	77.59	108.62
	57.70	.69	1.53	56.57	56.74	80.50	118.90
1-8 1.047 LB NG, NO BOOSTER							
	4.00	128.20	20.50	3.94	3.94	212.05	160.24
	6.05	- -	13.55	- -	5.96	- -	140.11
	9.99	12.80	8.21	9.84	9.84	149.48	123.64
	19.10	3.46	4.29	18.81	18.81	110.12	111.34
	28.20	1.79	2.91	27.77	27.77	88.71	107.58
	57.70	.69	1.42	56.82	56.82	82.59	106.40
1-9 1.031 LB NG, 46 G C4							
	4.02	159.17	28.23	3.92	3.92	281.36	273.38
	6.07	45.23	15.39	5.88	5.87	178.97	169.36
	10.00	12.02	7.93	9.60	9.57	126.34	112.47
	19.10	2.99	3.80	17.94	18.10	71.02	86.95
	28.30	1.53	- -	26.10	- -	51.63	- -
	57.70	.65	1.50	53.73	55.16	59.62	110.47

SUMMARY OF EXPERIMENTAL RESULTS

BASED ON INDIVIDUAL DATA POINTS

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ (PSI-MS/LB$^{1/3}$)	LAMBDA-P (FT/LB$^{1/3}$)	LAMBDA-I (FT/LB$^{1/3}$)	EQ-P (%)	EQ-I (%)
1-1 .953 LB NG 9 G C4							
	4.00	120.00	24.91	4.05	4.05	210.53	230.72
	6.05	- -	13.03	- -	6.11	- -	135.87
	9.99	9.87	8.00	10.07	10.08	107.79	122.88
	19.10	2.72	4.49	19.18	19.28	71.57	123.76
	28.20	1.72	3.09	28.38	28.46	86.13	122.29
	57.70	.76	1.60	58.19	58.26	109.38	131.20
1-2 1.219 LB NG, 23 G C4							
	4.00	132.00	26.11	3.71	3.72	184.42	223.29
	6.05	- -	15.75	- -	5.61	- -	165.34
	9.99	12.90	7.90	9.23	9.20	124.67	105.87
	19.10	3.09	4.75	17.46	17.63	70.15	118.85
	28.20	1.85	3.21	25.83	26.01	76.35	113.70
	57.70	.81	1.68	53.10	53.28	99.07	123.90

SUMMARY OF EXPERIMENTAL RESULTS

BASED ON INDIVIDUAL DATA POINTS

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ (PSI-MS/LB$^{1/3}$)	LAMBDA-P (FT/LB$^{1/3}$)	LAMBDA-I (FT/LB$^{1/3}$)	EQ-P (%)	EQ-I (%)
1-4	1.063 LB NG, 9 G C4						
	4.01	155.00	26.18	3.92	3.92	270.23	240.20
	6.06	- -	15.61	- -	5.91	- -	175.01
	10.00	13.40	- -	9.75	- -	155.73	- -
	19.10	2.74	4.49	18.50	18.59	65.18	117.36
	28.20	1.56	3.13	27.29	27.46	61.46	118.15
	57.70	.72	1.59	56.05	56.19	86.52	123.31
1-5	1.047 LB NG, 23 G C4						
	4.02	156.00	22.81	3.93	3.92	275.33	190.41
	6.07	49.10	12.60	5.92	5.88	203.61	122.13
	10.00	12.50	7.37	9.71	9.66	138.64	101.44
	19.10	2.82	4.37	18.28	18.48	66.74	111.76
	28.30	1.50	2.95	26.91	27.37	53.88	107.62
	57.70	.75	1.52	55.66	55.86	93.93	114.56
1-6	1.031 LB NG, NO BOOSTER						
	10.00	13.60	7.31	9.90	9.90	166.53	103.47
	19.10	2.81	4.18	18.91	18.91	73.34	107.50
	28.30	1.51	2.93	28.01	28.01	61.73	110.24
	57.70	.67	1.47	57.12	57.12	79.10	113.31

SUMMARY OF EXPERIMENTAL RESULTS

BASED ON INDIVIDUAL DATA POINTS

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ (PSI-MS/LB$^{1/3}$)	LAMBDA-P (FT/LB$^{1/3}$)	LAMBDA-I (FT/LB$^{1/3}$)	EQ-P (%)	EQ-I (%)
1-7 1.031 LB NG, 9 G C4							
	10.00	13.00	7.50	9.85	9.83	153.41	106.79
	19.10	3.25	4.22	18.76	18.77	96.26	107.93
	28.30	1.72	2.87	27.75	27.81	80.49	105.62
	57.70	.69	1.54	56.57	56.75	79.85	120.11
1-8 1.047 LB NG, NO BOOSTER							
	4.00	126.00	20.98	3.94	3.94	207.15	166.60
	6.05	- -	13.20	- -	5.96	- -	134.12
	9.99	13.50	8.69	9.84	9.84	161.73	135.42
	19.10	3.41	3.92	18.81	18.81	106.88	96.64
	28.20	1.72	2.91	27.77	27.77	80.70	107.44
	57.70	.71	1.48	56.82	56.82	86.92	112.69
1-9 1.031 LB NG, 46 G C4							
	4.02	147.00	27.89	3.92	3.92	251.02	267.75
	6.07	49.70	16.28	5.89	5.88	203.87	186.35
	10.00	12.80	7.28	9.63	9.52	140.01	97.44
	19.10	2.80	3.98	17.80	18.16	60.80	94.16
	28.30	1.45	- -	25.82	- -	44.09	- -
	57.70	.67	1.49	54.06	55.14	67.06	109.13

TEST DATA

	R	P	I
	(FT)	(PSIG)	(PSI-MS)
1-1	.953 LB NG 9 G C4		
	4.00	120.00	24.60
	6.05	- -	12.90
	9.99	9.87	7.93
	19.10	2.72	4.45
	28.20	1.72	3.06
	57.70	.76	1.58
1-2	1.219 LB NG, 23 G C4		
	4.00	132.00	28.10
	6.05	- -	17.00
	9.99	12.90	8.57
	19.10	3.09	5.15
	28.20	1.85	3.48
	57.70	.81	1.82
1-4	1.063 LB NG, 9 G C4		
	4.01	155.00	26.80
	6.06	- -	16.00
	10.00	13.40	- -
	19.10	2.74	4.61
	28.20	1.56	3.21
	57.70	.72	1.63
1-5	1.047 LB NG, 23 G C4		
	4.02	156.00	23.40
	6.07	49.10	13.00
	10.00	12.50	7.63
	19.10	2.82	4.52
	28.30	1.50	3.05
	57.70	.75	1.57
1-6	1.031 LB NG, NO BOOSTER		
	10.00	13.60	7.38
	19.10	2.81	4.22
	28.30	1.51	2.96
	57.70	.67	1.49
1-7	1.031 LB NG, 9 G C4		
	10.00	13.00	7.63
	19.10	3.25	4.29
	28.30	1.72	2.92
	57.70	.69	1.57

TEST DATA

R (FT)	P (PSIG)	I (PSI-MS)
1-8 1.047 LB NG, NO BOOSTER		
4.00	126.00	21.30
6.05	- -	13.40
9.99	13.50	8.82
19.10	3.41	3.98
28.20	1.72	2.95
57.70	.71	1.50
1-9 1.031 LB NG, 46 G C4		
4.02	147.00	28.60
6.07	49.70	16.80
10.00	12.80	7.65
19.10	2.80	4.19
28.30	1.45	- -
57.70	.67	1.56

SUMMARY OF EXPERIMENTAL RESULTS

CURVE FIT

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ ($PSI-MS/LB^{1/3}$)	LAMBDA-P ($FT/LB^{1/3}$)	LAMBDA-I ($FT/LB^{1/3}$)	EQ-P (%)	EQ-I (%)
2-1	1.969 LB NG. 18 G C						
	5.06	- -	27.07	- -	4.02	- -	263.41
	7.11	48.90	16.15	5.65	5.65	175.59	174.07
	11.10	14.14	8.86	8.80	8.80	123.76	119.60
	20.10	3.83	4.55	15.87	15.90	80.59	95.59
	29.30	2.05	3.22	23.10	23.18	68.68	96.73
	58.70	.99	2.01	46.48	46.55	106.00	132.36
2-2	1.969 L NG. 45 G C4						
	5.03	135.82	24.93	3.98	3.98	236.32	225.66
	7.08	- -	17.20	- -	5.59	- -	190.43
	11.00	14.93	- -	8.64	- -	126.78	- -
	20.10	4.09	5.54	15.67	15.78	88.32	129.16
	29.30	2.18	3.68	22.76	22.97	75.04	117.31
	58.70	.98	1.74	45.90	45.93	100.37	103.95

SUMMARY OF EXPERIMENTAL RESULTS

CURVE FIT

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ $(PSI-MS/LB^{1/3})$	LAMBDA-P $(FT/LB^{1/3})$	LAMBDA-I $(FT/LB^{1/3})$	EQ-P (%)	EQ-I (%)
2-4	2 LB NG, 18 G C4						
	5.04	- -	22.95	- -	3.98	- -	196.72
	7.09	- -	14.70	- -	5.60	- -	147.25
	11.00	16.73	8.67	8.68	8.67	151.78	113.25
	20.10	3.79	4.56	15.79	15.82	77.83	95.48
	29.30	1.91	3.21	22.93	23.06	57.34	95.31
	58.70	.88	1.85	46.11	46.27	78.18	115.65
2-5	1.969 LB NG, 45 G C4						
	5.07	- -	21.64	- -	4.00	- -	179.08
	7.12	51.62	15.21	5.62	5.61	185.56	156.07
	20.10	3.77	5.18	15.61	15.76	74.22	115.74
	29.30	1.97	3.50	22.60	22.94	58.60	108.31
	58.70	.91	1.71	45.69	45.90	81.52	101.22
2-6	1.984 LB NG, NO BOOSTER						
	4.98	130.39	- -	3.96	- -	220.96	- -
	7.03	47.52	13.59	5.59	5.59	164.58	129.20
	11.00	- -	8.74	- -	8.75	- -	116.31
	20.00	4.12	4.85	15.92	15.92	93.72	105.99
	29.20	2.14	3.34	23.24	23.24	76.48	102.60
	58.60	.88	1.68	46.64	46.64	80.69	101.55

SUMMARY OF EXPERIMENTAL RESULTS

CURVE FIT

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ $(PSI-MS/LB^{1/3})$	LAMBDA-P $(FT/LB^{1/3})$	LAMBDA-I $(FT/LB^{1/3})$	EQ-P (%)	EQ-I (%)
2-8	2 LB NG, 63 G C4						
	5.00	145.53	20.79	3.92	3.90	248.91	161.98
	7.05	- -	14.55	- -	5.49	- -	140.80
	11.00	14.51	- -	8.53	- -	117.05	- -
	20.10	3.87	4.90	15.39	15.53	75.09	104.00
	29.20	2.07	3.33	22.20	22.53	62.04	97.42
	58.70	.95	1.62	45.17	45.21	88.33	91.18
2-9	2 LB NG, 63 G C4						
	5.06	- -	20.91	- -	3.95	- -	166.29
	7.11	69.22	14.72	5.58	5.54	266.80	145.29
	11.10	17.80	- -	8.66	- -	164.35	- -
	20.10	4.12	5.03	15.45	15.55	85.79	108.64
	29.30	2.00	3.41	22.21	22.63	57.82	102.03
	58.70	.80	1.67	44.46	45.27	56.65	96.05

SUMMARY OF EXPERIMENTAL RESULTS

BASED ON INDIVIDUAL DATA POINTS

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ (PSI-MS/LB$^{1/3}$)	LAMBDA-P (FT/LB$^{1/3}$)	LAMBDA-I (FT/LB$^{1/3}$)	EQ-P (%)	EQ-I (%)
2-1	1.969 LB NG, 18 G C						
	5.06	- -	28.64	- -	4.03	- -	289.92
	7.11	47.80	15.56	5.65	5.64	170.41	163.54
	11.10	14.90	7.99	8.80	8.79	133.80	101.23
	20.10	3.67	4.94	15.86	15.92	74.04	109.14
	29.30	2.07	3.32	23.10	23.19	69.95	101.50
	58.70	.99	1.95	46.48	46.53	107.09	126.29
2-2	1.969 L NG, 45 G C4						
	5.03	137.00	24.91	3.98	3.98	239.19	225.37
	7.08	- -	18.34	- -	5.60	- -	212.16
	11.00	14.80	- -	8.63	- -	125.05	- -
	20.10	3.87	4.99	15.63	15.74	78.61	108.99
	29.30	2.36	3.57	22.86	22.95	89.85	111.75
	58.70	.96	1.87	45.85	46.02	95.15	116.24

SUMMARY OF EXPERIMENTAL RESULTS

BASED ON INDIVIDUAL DATA POINTS

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ (PSI-MS/LB$^{1/3}$)	LAMBDA-P (FT/LB$^{1/3}$)	LAMBDA-I (FT/LB$^{1/3}$)	EQ-P (%)	EQ-I (%)
2-4 2 LB NG, 18 G C4							
	5.04	- -	23.83	- -	3.98	- -	210.37
	7.09	- -	14.52	- -	5.60	- -	144.26
	11.00	16.80	7.87	8.68	8.66	152.67	96.78
	20.10	3.73	4.84	15.78	15.83	75.31	104.70
	29.30	1.94	3.34	22.94	23.07	59.42	101.44
	58.70	.88	1.80	46.10	46.25	77.57	110.68
2-5 1.969 LB NG, 45 G C4							
	5.07	- -	23.63	- -	4.01	- -	208.11
	7.12	51.50	14.47	5.62	5.60	184.99	143.57
	20.10	3.83	4.88	15.62	15.73	76.92	105.32
	29.30	1.93	3.27	22.57	22.89	55.92	96.92
	58.70	.91	1.87	45.70	46.02	82.47	116.24

SUMMARY OF EXPERIMENTAL RESULTS

BASED ON INDIVIDUAL DATA POINTS

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ (PSI-MS/LB$^{1/3}$)	LAMBDA-P (FT/LB$^{1/3}$)	LAMBDA-I (FT/LB$^{1/3}$)	EQ-P (%)	EQ-I (%)
2-6	1.984 LB NG, NO BOOSTER						
	4.98	131.00	- -	3.96	- -	222.36	- -
	7.03	47.20	14.64	5.59	5.59	163.16	146.19
	11.00	- -	8.28	- -	8.75	- -	106.51
	20.00	4.12	4.65	15.92	15.92	93.58	99.12
	29.20	2.15	3.24	23.24	23.24	77.30	97.81
	58.60	.88	1.77	46.64	46.64	80.29	110.01
2-8	2 LB NG, 63 G C4						
	5.00	147.00	21.15	3.92	3.90	252.48	166.82
	7.05	- -	14.71	- -	5.49	- -	143.52
	11.00	14.30	- -	8.52	- -	114.35	- -
	20.10	3.69	4.79	15.33	15.52	67.59	100.14
	29.20	2.23	3.13	22.35	22.47	74.37	88.41
	58.70	.93	1.71	45.09	45.31	83.59	99.31

SUMMARY OF EXPERIMENTAL RESULTS

BASED ON INDIVIDUAL DATA POINTS

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ $(PSI-MS/LB^{1/3})$	LAMBDA-P $(FT/LB^{1/3})$	LAMBDA-I $(FT/LB^{1/3})$	EQ-P (%)	EQ-I (%)
2-9	2 LB NG, 63 G C4						
	5.06	- -	21.72	- -	3.95	- -	177.42
	7.11	66.70	14.88	5.58	5.54	253.78	147.96
	11.10	19.30	- -	8.68	- -	185.03	- -
	20.10	3.93	4.77	15.40	15.52	77.48	99.59
	29.30	1.99	3.13	22.20	22.55	56.91	88.89
	58.70	.81	1.83	44.51	45.44	58.35	110.47

TEST DATA

	R (FT)	P (PSIG)	I (PSI-MS)
2-1 1.969 LB NG, 18 G C			
	5.06	- -	36.00
	7.11	47.80	19.60
	11.10	14.90	10.10
	20.10	3.67	6.24
	29.30	2.07	4.20
	58.70	.99	2.46
2-2 1.969 L NG, 45 G C4			
	5.03	137.00	31.50
	7.08	- -	23.20
	11.00	14.80	- -
	20.10	3.87	6.37
	29.30	2.36	4.56
	58.70	.96	2.38
2-4 2 LB NG, 18 G C4			
	5.04	- -	30.20
	7.09	- -	18.40
	11.00	16.80	10.00
	20.10	3.73	6.14
	29.30	1.94	4.24
	58.70	.88	2.28
2-5 1.969 LB NG, 45 G C4			
	5.07	- -	29.90
	7.12	51.50	18.40
	20.10	3.83	6.24
	29.30	1.93	4.18
	58.70	.91	2.38
2-6 1.984 LB NG, NO BOOSTER			
	4.98	131.00	- -
	7.03	47.20	18.40
	11.00	- -	10.40
	20.00	4.12	5.84
	29.20	2.15	4.07
	58.60	.88	2.23

TEST DATA

	R (FT)	P (PSIG)	I (PSI-MS)
2-8 2 LB NG, 63 G C4			
	5.00	147.00	27.10
	7.05	- -	18.90
	11.00	14.30	- -
	20.10	3.69	6.20
	29.20	2.23	4.07
	58.70	.93	2.21
2-9 2 LB NG, 63 G C4			
	5.06	- -	27.80
	7.11	66.70	19.10
	11.10	19.30	- -
	20.10	3.93	6.18
	29.30	1.99	4.07
	58.70	.81	2.36

SUMMARY OF EXPERIMENTAL RESULTS

CURVE FIT

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ (PSI-MS/LB$^{1/3}$)	LAMBDA-P (FT/LB$^{1/3}$)	LAMBDA-I (FT/LB$^{1/3}$)	EQ-P (%)	EQ-I (%)
4-1	3.969 LB NG, 36 G C4						
	6.03	171.82	23.36	3.80	3.79	283.63	189.90
	8.08	75.06	17.33	5.08	5.08	223.99	169.71
	12.00	26.96	- -	7.55	- -	192.02	- -
	21.10	- -	6.52	- -	13.24	- -	129.91
	30.30	- -	4.51	- -	19.01	- -	121.94
	59.70	1.31	2.26	37.42	37.44	105.69	113.93
4-2	3.922 LB NG, 91 G C4						
	6.03	163.16	21.53	3.79	3.78	263.32	164.56
	8.08	- -	16.08	- -	5.05	- -	148.74
	12.00	22.18	- -	7.50	- -	144.79	- -
	21.10	- -	6.17	- -	13.15	- -	118.03
	30.30	3.14	4.31	18.78	18.86	90.16	112.30
	59.70	1.28	2.19	37.06	37.14	97.24	107.65
4-3	4.047 LB NG, 36 G C4						
	6.03	164.22	20.52	3.77	3.76	261.14	151.17
	8.08	64.33	15.35	5.05	5.04	179.17	137.39
	12.00	20.98	10.37	7.49	7.48	133.31	123.53
	21.10	- -	5.93	- -	13.15	- -	110.79
	30.30	2.93	4.15	18.83	18.87	79.09	105.93
	59.70	1.25	2.12	37.15	37.17	92.43	102.31

SUMMARY OF EXPERIMENTAL RESULTS

CURVE FIT

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ $(PSI\text{-}MS/LB^{1/3})$	LAMBDA-P $(FT/LB^{1/3})$	LAMBDA-I $(FT/LB^{1/3})$	EQ-P (%)	EQ-I (%)
4-4	4.125 LB NG, 36 G C4						
	6.03	146.42	18.91	3.75	3.74	218.52	130.58
	8.08	61.60	- -	5.01	- -	166.02	- -
	12.00	21.64	9.38	7.44	7.43	136.57	103.89
	21.10	- -	5.58	- -	13.05	- -	99.48
	30.30	3.26	4.10	18.74	18.75	96.59	103.11
	59.70	1.34	2.43	36.96	36.99	107.31	124.94
4-5	3.969 LB NG, 91 G C4						
	5.99	154.43	23.41	3.75	3.74	235.93	187.28
	8.04	- -	17.33	- -	5.02	- -	166.89
	12.00	20.80	- -	7.46	- -	130.49	- -
	21.10	5.81	6.47	13.05	13.11	97.04	126.82
	30.20	3.05	4.49	18.61	18.75	82.61	118.94
	59.60	1.27	2.25	36.84	36.96	94.78	110.95
4-6	4.078 LB NG, NO BOOSTER						
	6.00	167.12	21.74	3.76	3.76	263.99	166.13
	8.05	60.87	16.22	5.04	5.04	165.84	150.38
	12.00	- -	10.89	- -	7.51	- -	134.43
	21.10	4.88	6.21	13.21	13.21	73.45	119.77
	30.20	2.60	4.34	18.90	18.90	62.28	114.06
	59.70	1.24	2.20	37.56	37.37	94.33	109.16

SUMMARY OF EXPERIMENTAL RESULTS

CURVE FIT

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ $(PSI-MS/LB^{1/3})$	LAMBDA-P $(FT/LB^{1/3})$	LAMBDA-I $(FT/LB^{1/3})$	EQ-P (%)	EQ-I (%)
4-7	4.063 LB NG, NO BOOSTER						
	6.00	143.71	20.86	3.76	3.76	215.36	155.28
	8.05	70.94	15.62	5.04	5.04	203.21	141.47
	12.00	28.39	- -	7.52	- -	203.47	- -
	21.10	- -	6.04	- -	13.22	- -	114.93
	30.20	- -	4.24	- -	18.93	- -	110.21
	59.70	1.18	2.17	37.41	37.41	82.84	106.80
4-8	4.094 LB NG, 127 G C4						
	5.96	182.14	27.96	3.69	3.68	282.13	247.98
	8.01	68.36	18.43	4.93	4.93	180.75	180.77
	12.00	21.10	- -	7.34	- -	126.77	- -
	21.00	5.68	5.79	12.72	12.78	86.31	102.43
	30.20	2.94	4.06	18.19	18.36	71.91	98.60
	59.60	1.30	2.36	36.21	36.39	94.92	116.79
4-9	4.125 LB NG, 100 G C4						
	6.00	- -	21.62	- -	3.70	- -	161.14
	8.05	53.32	16.11	4.94	4.95	131.97	145.28
	12.00	18.58	- -	7.35	- -	106.46	- -
	21.10	5.52	6.15	12.86	12.93	84.76	114.49
	30.20	3.02	4.30	18.37	18.49	78.20	108.74
	59.70	1.38	2.18	36.58	36.53	112.19	103.82

SUMMARY OF EXPERIMENTAL RESULTS

BASED ON INDIVIDUAL DATA POINTS

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ $(PSI\text{-}MS/LB^{1/3})$	LAMBDA-P $(FT/LB^{1/3})$	LAMBDA-I $(FT/LB^{1/3})$	EQ-P (%)	EQ-I (%)
4-1	3.969 LB NG, 36 G C4						
	6.03	166.00	23.58	3.80	3.79	270.31	193.08
	8.08	80.40	18.30	5.09	5.08	245.33	185.86
	12.00	26.00	- -	7.55	- -	182.76	- -
	21.10	- -	5.97	- -	13.23	- -	112.96
	30.30	- -	4.24	- -	19.00	- -	111.00
	59.70	1.31	2.45	37.42	37.47	106.23	129.32
4-2	3.922 LB NG, 91 G C4						
	6.03	164.00	21.28	3.79	3.77	265.23	161.37
	8.08	- -	16.90	- -	5.06	- -	161.88
	12.00	21.90	- -	7.50	- -	142.18	- -
	21.10	- -	5.78	- -	13.12	- -	105.99
	30.30	3.18	4.27	18.79	18.66	92.69	110.81
	59.70	1.27	2.27	37.05	37.17	96.00	113.78

SUMMARY OF EXPERIMENTAL RESULTS

BASED ON INDIVIDUAL DATA POINTS

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ (PSI-MS/LB$^{1/3}$)	LAMBDA-P (FT/LB$^{1/3}$)	LAMBDA-I (FT/LB$^{1/3}$)	EQ-P (%)	EQ-I (%)
4-3	4.047 LB NG, 36 G C4						
	6.03	156.00	21.48	3.77	3.77	243.16	163.39
	8.08	71.20	16.29	5.05	5.04	204.86	151.73
	12.00	19.90	9.53	7.48	7.47	123.79	107.50
	21.10	- -	5.52	- -	13.14	- -	98.64
	30.30	2.93	4.07	18.83	18.87	78.91	102.78
	59.70	1.25	2.27	37.15	37.20	93.23	114.05
4-4	4.125 LB NG, 36 G C4						
	6.03	148.00	19.47	3.75	3.74	221.78	137.16
	8.08	60.90	- -	5.01	- -	163.53	- -
	12.00	21.50	8.59	7.44	7.42	135.37	89.96
	21.10	- -	5.93	- -	13.06	- -	109.61
	30.30	3.30	4.17	18.75	18.76	99.10	105.80
	59.70	1.33	2.39	36.95	36.99	105.94	121.50

SUMMARY OF EXPERIMENTAL RESULTS

BASED ON INDIVIDUAL DATA POINTS

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ (PSI-MS/LB$^{1/3}$)	LAMBDA-P (FT/LB$^{1/3}$)	LAMBDA-I (FT/LB$^{1/3}$)	EQ-P (%)	EQ-I (%)
4-5	3.969 LB NG, 91 G C4						
	5.99	153.00	22.66	3.75	3.74	232.85	177.18
	8.04	- -	18.87	- -	5.02	- -	192.70
	12.00	21.40	- -	7.47	- -	135.93	- -
	21.10	5.70	6.14	13.04	13.09	93.55	116.48
	30.20	3.03	4.22	18.61	18.72	81.60	107.64
	59.60	1.28	2.39	36.86	37.02	96.20	122.10
4-6	4.078 LB NG, NO BOOSTER						
	6.00	168.00	22.47	3.76	3.76	265.92	175.67
	8.05	60.60	17.59	5.04	5.04	164.89	172.08
	12.00	- -	9.83	- -	7.51	- -	113.73
	21.10	4.78	5.99	13.21	13.21	70.66	113.26
	30.20	2.67	4.11	18.90	18.90	65.92	104.87
	59.70	1.23	2.38	37.56	37.37	92.79	122.83

SUMMARY OF EXPERIMENTAL RESULTS

BASED ON INDIVIDUAL DATA POINTS

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ $(PSI-MS/LB^{1/3})$	LAMBDA-P $(FT/LB^{1/3})$	LAMBDA-I $(FT/LB^{1/3})$	EQ-P (%)	EQ-I (%)
4-7	4.063 LB NG, NO BOOSTER						
	6.00	138.00	20.30	3.76	3.76	203.80	148.34
	8.05	76.90	16.80	5.04	5.04	225.82	159.64
	12.00	27.20	- -	7.52	- -	192.21	- -
	21.10	- -	5.73	- -	13.22	- -	105.71
	30.20	- -	4.07	- -	18.93	- -	103.27
	59.70	1.17	2.27	37.41	37.41	81.66	115.03
4-8	4.094 LB NG, 127 G C4						
	5.96	167.00	28.76	3.68	3.69	248.94	260.20
	8.01	69.90	17.77	4.93	4.93	186.35	169.88
	12.00	26.00	- -	7.38	- -	171.04	- -
	21.00	5.06	5.67	12.63	12.77	68.57	98.96
	30.20	2.70	4.25	18.05	18.40	58.78	106.03
	59.60	1.38	2.33	36.34	36.37	109.68	114.02

SUMMARY OF EXPERIMENTAL RESULTS

BASED ON INDIVIDUAL DATA POINTS

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ $(PSI\text{-}MS/LB^{1/3})$	LAMBDA-P $(FT/LB^{1/3})$	LAMBDA-I $(FT/LB^{1/3})$	EQ-P (%)	EQ-I (%)
4-9	4.125 LB NG, 100 G C4						
	6.00	- -	21.49	- -	3.69	- -	159.52
	8.05	52.20	16.93	4.94	4.96	128.23	158.05
	12.00	19.60	- -	7.36	- -	115.17	- -
	21.10	5.19	5.91	12.82	12.92	75.16	107.39
	30.20	3.12	4.02	18.40	18.46	83.69	97.62
	59.70	1.38	2.32	36.58	36.59	111.83	114.40

TEST DATA

	R (FT)	P (PSIG)	I (PSI-MS)
4-1 3.969 LB NG, 36 G C4			
	6.03	166.00	37.50
	8.08	80.40	29.10
	12.00	26.00	- -
	21.10	- -	9.52
	30.30	- -	6.77
	59.70	1.31	3.91
4-2 3.922 LB NG, 91 G C4			
	6.03	164.00	34.00
	8.08	- -	27.00
	12.00	21.90	- -
	21.10	- -	9.29
	30.30	3.18	6.86
	59.70	1.27	3.65
4-3 4.047 LB NG, 36 G C4			
	6.03	156.00	34.40
	8.08	71.20	26.10
	12.00	19.90	15.30
	21.10	- -	8.86
	30.30	2.93	6.53
	59.70	1.25	3.65
4-4 4.125 LB NG, 36 G C4			
	6.03	148.00	31.40
	8.08	60.90	- -
	12.00	21.50	13.90
	21.10	- -	9.57
	30.30	3.30	6.73
	59.70	1.33	3.85
4-5 3.969 LB NG, 91 G C4			
	5.99	153.00	36.30
	8.04	- -	30.20
	12.00	21.40	- -
	21.10	5.70	9.90
	30.20	3.03	6.81
	59.60	1.28	3.85

TEST DATA

	R (FT)	P (PSIG)	I (PSI-MS)
4-6 4.078 LB NG, NO BOOSTER			
	6.00	168.00	35.90
	8.05	60.60	28.10
	12.00	- -	15.70
	21.10	4.78	9.57
	30.20	2.67	6.57
	59.70	1.23	3.80
4-7 4.063 LB NG, NO BOOSTER			
	6.00	138.00	32.40
	8.05	76.90	26.80
	12.00	27.20	- -
	21.10	- -	9.14
	30.20	- -	6.49
	59.70	1.17	3.63
4-8 4.094 LB NG, 127 G C4			
	5.96	167.00	46.50
	8.01	69.90	28.90
	12.00	26.00	- -
	21.00	5.06	9.32
	30.20	2.70	6.97
	59.60	1.38	3.81
4-9 4.125 LB NG, 100 G C4			
	6.00	- -	34.90
	8.05	52.20	27.50
	12.00	19.60	- -
	21.10	5.19	9.65
	30.20	3.12	6.57
	59.70	1.38	3.78

SUMMARY OF EXPERIMENTAL RESULTS

BASED ON INDIVIDUAL DATA POINTS

TEST TYPE	R (FT)	P (PSIG)	$I/W^{1/3}$ (PSI-MS/LB$^{1/3}$)	LAMBDA-P (FT/LB$^{1/3}$)	LAMBDA-I (FT/LB$^{1/3}$)	EQ-P (%)	EQ-I (%)
C-1,2,3 2 LB C4							
	4.00	131.00	20.34	2.95	2.95	91.44	108.02
	6.05	55.40	11.20	4.46	4.46	101.62	69.12
	9.99	18.20	9.80	7.36	7.36	103.91	110.03
	19.05	5.54	5.08	14.04	14.04	110.89	95.12
	28.25	2.78	3.29	20.81	20.81	95.72	85.18
	57.65	1.07	1.88	42.48	42.48	96.96	104.18
	4.00	129.00	20.34	2.95	2.95	89.56	108.02
	6.05	51.50	10.83	4.46	4.46	92.43	65.41
	9.99	18.20	8.99	7.36	7.36	103.91	95.66
	19.05	[illegible]	4.84	14.04	14.04	75.82	88.27
	28.25	[illegible]	3.46	20.81	20.81	75.39	92.37
	57.65	[illegible]	1.75	42.48	42.48	67.94	93.92
	4.00	[illegible]	17.98	2.95	2.95	93.34	87.71
	6.05	- -	11.72	- -	4.46	- -	74.45
	9.99	20.60	8.03	7.36	7.36	123.45	79.72
	19.05	4.77	4.91	14.04	14.04	84.50	98.18
	28.25	2.57	3.35	20.81	20.81	81.27	87.55
	57.65	.95	1.66	42.48	42.48	73.28	86.34

TEST DATA

	R (FT)	P (PSIG)	I (PSI-MS)
C-1,2,3 2 LB C4			
	4.00	131.00	27.60
	6.05	55.40	15.20
	9.99	18.20	13.30
	19.05	5.54	6.89
	28.25	2.78	4.46
	57.65	1.07	2.55
	4.00	129.00	27.60
	6.05	51.50	14.70
	9.99	18.20	12.20
	19.05	4.50	6.57
	28.25	2.48	4.70
	57.65	.92	2.38
	4.00	133.00	24.40
	6.05	- -	15.90
	9.99	20.60	10.90
	19.05	4.77	6.66
	28.25	2.57	4.54
	57.65	.95	2.25

APPENDIX C

TNT EQUIVALENCY COMPUTATION PROCEDURE

C.1 Computation Procedure

The computational procedure used to obtain TNT equivalencies is illustrated in this appendix. TNT equivalency for pressure is defined as the ratio of charge weight (i.e., TNT weight/test explosive weight) that will give the same peak pressure at the same radial distance from each charge. Similarly, the TNT equivalency for impulse is defined as the ratio of charge weights that will give the same positive impulse at the same radial distances. Since the booster, used to detonate the test explosive, propellant, or pyrotechnic may be of the order of 10 percent of the test material weight it is necessary to account for its contribution to the explosive output (i.e., peak pressure and impulse).

The symbols used in this discussion are:

W	Weight, lbs
R	Radial distance from charge, ft
$\lambda = R/W^{1/3}$	Scaled distance, ft/lb$^{1/3}$
P	Peak overpressure, psig
I	Positive impulse, psi-msec
E	TNT equivalency, percent

These subscripts and superscripts are self-explanatory when applied to the above symbols:

S	Test sample
B	Booster
TNT	TNT explosive
I	Impulse
P	Pressure
*	Quantity is not adjusted for booster weight
TOT	Total charge weight, booster plus sample

Pressure equivalency is determined by first measuring the quantities W_S, R, and P_{SB}. Where P_{SB} is the peak pressure measured when the test sample was detonated with a C4 booster, it includes an energy contribution from both the C4 booster and the test sample.

One must first approximate an equivalent booster weight, in terms of the test sample weight, so that its weight can be included in the total charge weight. The approximation is found by obtaining λ_{TNT}, from Figure C1, for $P_{SB} = P_{TNT}$.

The first approximation for TNT pressure equivalency is then

$$E_P^* = W_{TNT}/W_S = (\lambda_S/\lambda_{TNT})^3$$

where

$$\lambda_S = R/W_S^{1/3}$$

and

$$\lambda_{TNT} = R/W_{TNT}^{1/3}.$$

Since the pressures are to be equal at the same radial distance the R's cancel in the above equation. One applies this approximated equivalency, E_P^*, to the weight of the booster to obtain the total charge weight

$$W_{TOT} = W_S + (1/E_P^*)\, W_B\, (1.25).$$

A factor of 1.25 is applied to the C4 booster weight to obtain its equivalent TNT weight.

A new λ is now computed from

$$\lambda_{TOT} = R/W_{TOT}^{1/3}$$

and a corrected pressure TNT equivalency is computed.

$$E_P = W_{TNT}/W_{TOT} = (\lambda_{TOT}/\lambda_{TNT})^3$$

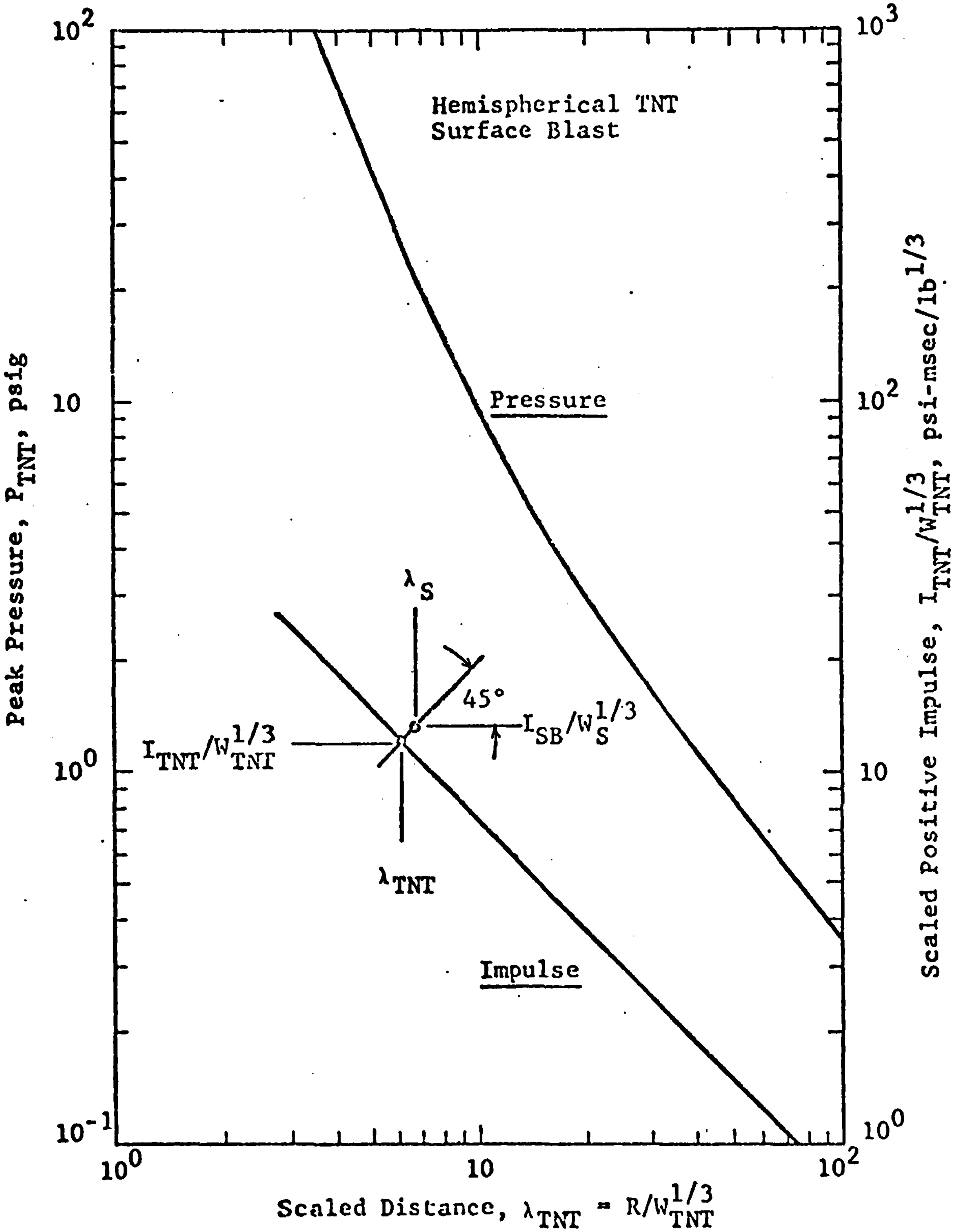


Figure C1 TNT Pressure and Impulse

The P subscript indicates a scale distance for pressure and is computed from the revised sample weight. This iterative process can be repeated using the revised value of E_P to recompute the weight of the booster in terms of the sample weight, etc. However the second iteration has a small effect on equivalency.

Impulse equivalency is determined by first measuring W_S, R, and I_{SB}. Where I_{SB} is the impulse measured when the test sample, was detonated with a C4 booster. One must first approximate an equivalent booster weight so that its weight can be included in the total charge weight. The approximation is found by locating the data point $I_{SB}/W^{1/3}$: λ_S on Figure C1. A 45 deg line is drawn through this data point to intersect with the TNT impulse curve. Values of λ_{TNT} and $I_{TNT}/W^{1/3}$ are read at the intersection of the two straight lines. These values give the equivalent TNT weight for equal impulses and radial distances.

At the data point $I_{SB}/W_S^{1/3}$ and λ_S let

$$a_S = I_{SB}/W_S^{1/3} \text{ or } I_{SB} = a_S W_S{}^{1/3}$$

and

$$\lambda_S = R/W_S^{1/3} \quad \text{or } R = \lambda_S W_S^{1/3}.$$

For equal impulses

$$I_{SB} = I_{TNT}$$

or

$$a_S W_S^{1/3} = a_{TNT} W_{TNT}^{1/3}$$

and for equal radial distances

$$\lambda_S W_S^{1/3} = \lambda_{TNT} W_{TNT}^{1/3}.$$

Divide these two equations and get

$$\frac{a_S}{a_{TNT}} = \frac{\lambda_S}{\lambda_{TNT}}$$

Take the log of the above equation

$$\log a_S - \log a_{TNT} = \log \lambda_S - \log \lambda_{TNT}.$$

This equation shows that a 45 deg construction line on a log-log plot will intersect the impulse curve and data point in such a way as to satisfy the conditions of equal positive impulses at the same radial distance.

The first approximation for TNT impulse equivalency is

$$E_I^* = W_{TNT}/W_S$$

$$E_I^* = (I_{SB}/W_S^{1/3})^3 \ / \ (I_{TNT}/W_{TNT}^{1/3})^3$$

Since $I_{SB} = I_{TNT}$ they cancel in the above equation.

One applies this approximated equivalency, E_I^*, to the weight of the booster to obtain the total charge weight

$$W_{TOT} = W_S + (1/E_I^*)\ W_B(1.25).$$

A new scaled distance

$$\lambda_{TOT} = R/W_{TOT}^{1/3}$$

and scaled impulse is then computed

$$I_{SB}/W_{TOT}^{1/3}$$

This data point is now located on Figure C1 and new $I_{TNT}/W_{TNT}^{1/3}$ and λ_{TNT} values are determined from the 45 deg line intersection method described.

The corrected impulse equivalency then becomes

$$E_I = W_{TNT}/W_{TOT}$$

$$E_I = (I_{SB}/W_{TOT}^{1/3})^3/(I_{TNT}/W_{TNT}^{1/3})^3.$$

C.2 Computerized Calculations

The TNT equivalencies of N-5 explosive are determined by use of a computer program. The first step in the program is to fit a curve to the test data using the method of least squares. To do this, the pressures with their corresponding gage distances (and similarly, impulses with their distances) are entered into the program as input data. Scaled distances are then obtained by dividing the gage distances by the cube root of the charge weight. Using polynomial fits of the first and second order, the experimental data are curve fitted in the log-log plane. Where the input consists of experimental data from more than one test conducted under identical conditions, the pressure and impulse values are averaged before the curve fit is performed. Impulse input is converted to scaled impulse by dividing by the cube root of the charge weight. This is performed before averaging or curve fitting is done.

The best curve fitted to the data points is based on that polynomial where the deviations of the data point from the curve is less than 10 percent. If a point has more than a 10 percent deviation, both the pressure and impulse values are rejected. After a point is rejected the curve fit calculations are repeated and a new curve to fit the remaining data points is derived.

The output from this section of the computer program consists of the standard deviation, the percent error of each data point and the coefficient for each of the polynomial fits based both on a point by point fit and for averaged data. When the difference in the standard deviation is very small and when the percent error for both the linear and quadratic curves is under 10 percent, the first order, or linear curve is preferred.

Having chosen the curve which best describes the test data, pressure and impulse values with their corresponding gage distances (minus the points excluded by the curve fitting procedure) are entered into the program along with the appropriate curve coefficient. The TNT equivalence is determined twice; once using points from the fitted curve at scaled distances corresponding to the gage locations, and once using the actual data point. This is done for both pressure and impulse data.

In the program, the TNT pressure and impulse curves versus scaled distance appear as polynomial expressions. To determine the pressure equivalency, the TNT scaled distance at a pressure equal to the test pressure is determined from this equation. The TNT equivalency at each pressure data point is computed as the curve of the ratio of the scaled distance of the test data to the TNT scaled distance.

A correction is made to the equivalency calculation to include the weight of the booster in the total weight. The TNT equivalency is then recomputed on the basis of the corrected weight. This is an iterative process and continues until the change in the ratio of the scaled distance to the TNT scaled distance is negligible.

A similar procedure is followed for impulse data. Since scaled impulse is used rather than actual impulse, a correction in the total weight of the explosive to account for the booster weight involved making corrections to the scaled impulse as well as the scaled distance.

The computer output for the pressure tests includes, for the averaged and curve fitted data, scaled distance, corrected scaled distance, pressure, total weight and TNT equivalency at each gage location. Output based on raw data includes scaled distance, corrected scaled distance, input pressure, TNT equivalency and gage distance at each data point. The output for the impulse tests is similar with the exception that scaled impulse and corrected scaled impulse are included.

APPENDIX D

<u>INSTRUMENTATION</u>

D.1 Instrumentation

Pressure-time functions were monitored at six locations. The pressure-time signals were later integrated to produce impulse-time functions. Data signals were recorded on magnetic tape and reproduced on an oscillograph recorder. The following subsections contain a brief description of the instrumentation equipment and calibration technique employed on the test program.

D.2 Pressure Measuring Systems

The pressure measuring systems employed in the test program were manufactured by Photocon Research Products (PRP). These systems consist of three elements: the Dynagage (DG605D), a transmission line (RG58A/U), and the pressure transducer (Type 752A).

The PRP Type 752 transducer used to form the blast line have dynamic ranges of 0 to 5, 10, 20, 40, 200 and 500 psig. The maximum usable frequency response is 0 to 10 KHz. The normal voltage output is about 10 volts for full scale applied pressure. The diaphram of the transducer, in conjunction with an insulated stationary electrode, forms an electrical capacitor. The pressure to be measured is applied to the diaphram, causing a change in capacitance proportional to the applied pressure. The transducer capacitance and a built-in inductance form a tuned radio-frequency circuit. The tuned circuit is a line-coupled, by means of a low impedance cable, to a Dynagage system consisting of an oscillator-detector circuit and a cathode-follower amplifier. The changes in capacitance produce changes in the diode detector impedance, and thereby produce a signal voltage proportional to the applied pressure.

The transducers were removed from their water-cooled flame shields and placed in electrically insulated mounting adapters. The adapters were designed to provide flush mounting of the diaphragms. The electrical insulation material was used to break ground loops, thus reducing interference caused by stray pickup and inter-carrier beats.

The transducers were installed flush with the ground surface in steel mounting plates. The mounting plates were staked to the ground and the area adjacent to the mounting plates was graded to form a relatively smooth flat test area. Pressure measurements were made at six stations along the blast gage line. The transmission lines were run underground in the near-field and above-ground in the farfield, to the instrumentation trailer. The instrumentation trailer was located about 400 feet from the test area.

D.3 Recording Instrument

Hewlett Packard (HP) Model 8875A differential amplifiers were used to condition the data signals for magnetic tape recording. The units were used to provide a voltage gain and impedance match between the pressure measuring system and magnetic tape recorder.

The magnetic tape recorder used was an Ampex Model CP-100. This unit is a 14 channel instrumentation recorder, equipped with 13FM channels of electronics for data recording and a single direct channel for time base recording. The electrical performance characteristics for the CP-100 recorder conforms to the IRIG Intermediate Band specifications.

The data signals were dual recorded by using two tape channels to record the output of each pressure measuring system. The primary channels were adjusted so that the anticipated data signal levels would produce a full scale recording. The secondary channels were provided for "backup" for the case where the actual signals were greater than anticipated. The sensitivities of these channels were adjusted so that the anticipated data signals would produce a one-fifth of full-scale recording. The instrumentation equipment proceeding the recorder had the required dynamic range to accommodate both recording levels.

D.4 Data Reproduction

Oscillograph reproductions of the magnetic tape recordings were made by employing Consolidated Electrodynamics Corp. (CEC

Type 1-172 Driver Amplifiers to drive a CEC Type 5-124 Recording Oscillograph. The oscillograph was equipped with CEC Type 7-363 galvanometers.

The pressure data were recorded at a tape speed of 60 ips and reproduced at a tape speed of 1-7/8 ips, resulting in a frequency division of 32. The oscillograph paper speed was 32 ips. For these conditions, the oscillograph has a horizontal resolution of 976 μsec/in. and an effective frequency response from dc to 20 KHz, referred to real time.

The pressure impulse data was obtained by an electrical integration of the pressure-time signals. The signal voltage at the output of the tape recorder is an electrical analog of the pressure-time history. This signal was used as input to a Tektronix Type O operational amplifier, where the integration was performed. The integrated signals were amplified and in turn, recorded on the oscillograph recorder.

D.5 Block Diagram

A simplified block diagram of the record/reproduce instrumentation system is shown in Figure D1. A single data channel is shown. In the test program, six identical pressure recording channels were used.

In addition to the equipment previously described, the monitoring and signal control equipment is shown. The data channels were monitored and an electrical calibration signal was recorded on each data track immediately preceding each test run. The electrical calibration signal is a voltage simulation of a predetermined pressure and impulse level. This signal is used in data reduction and to verify the integrity of the record/reproduce system.

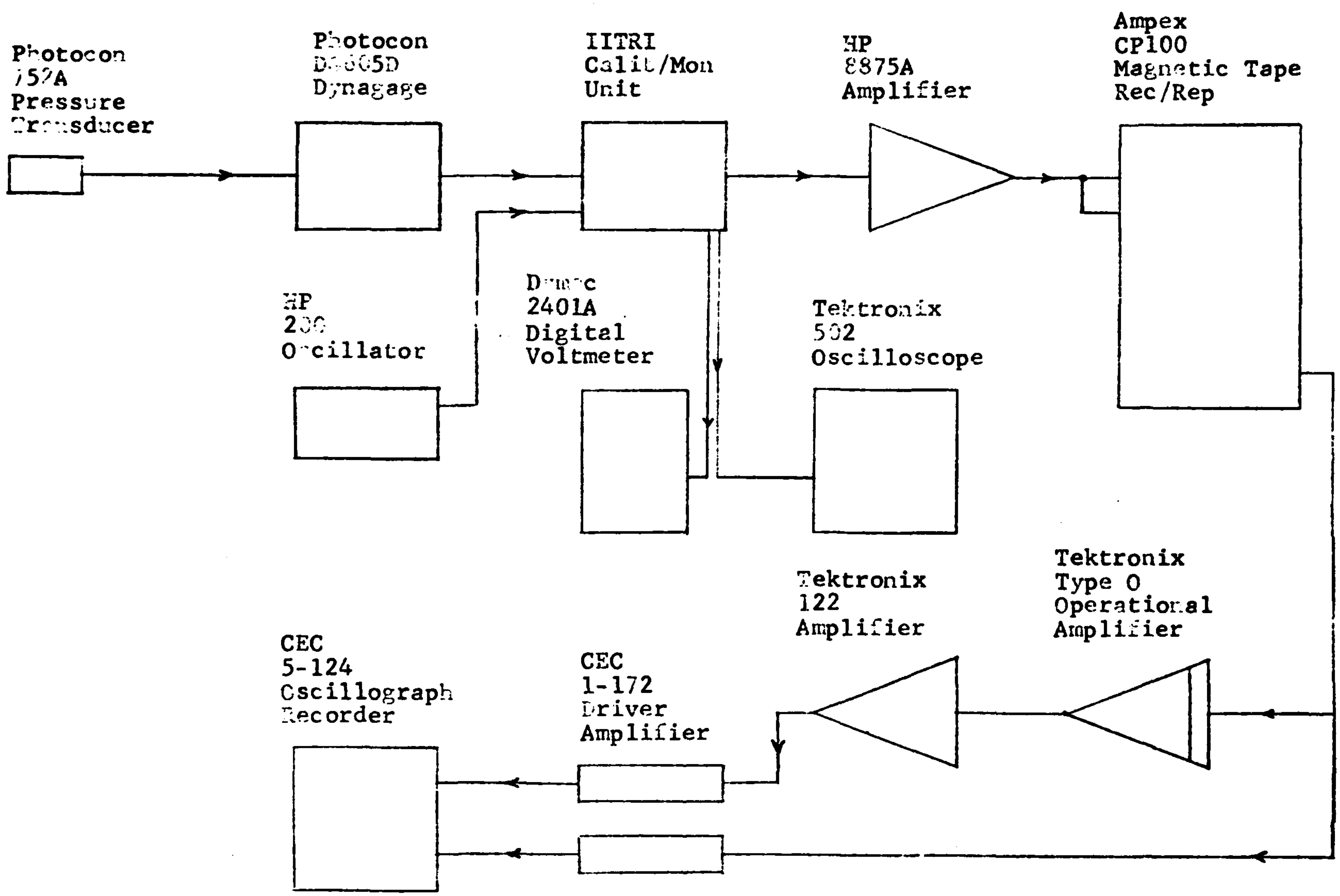


Figure D1 Block Diagram of Record/Reproduce Instrumentation

D.6 Calibration Procedures

The purpose of the pre-test calibration series was to establish sensitivity factors for each pressure measuring system. In the pre-test calibrations, a precisely known pressure was applied to the transducer. The applied pressure caused a voltage rise at the output of the Dynagage Amplifier. The sensitivity factor (k) is the output voltage from the Dynagage (V) divided by the applied pressure P.

$$K = \frac{V}{P} \text{ (Volts/psi)}$$

The Photocon systems were calibrated at five points in the test range. The quantity K for the range is the arithmetic mean of the values of K determined at all the points.

Field calibration tests were performed to verify the accuracy of the pressure measuring systems. The field calibration consisted of detonating a bare hemispherical charge of C4 on a steel witness plate. The output of the measuring system was compared with previously established pressure-distance curves for C4.